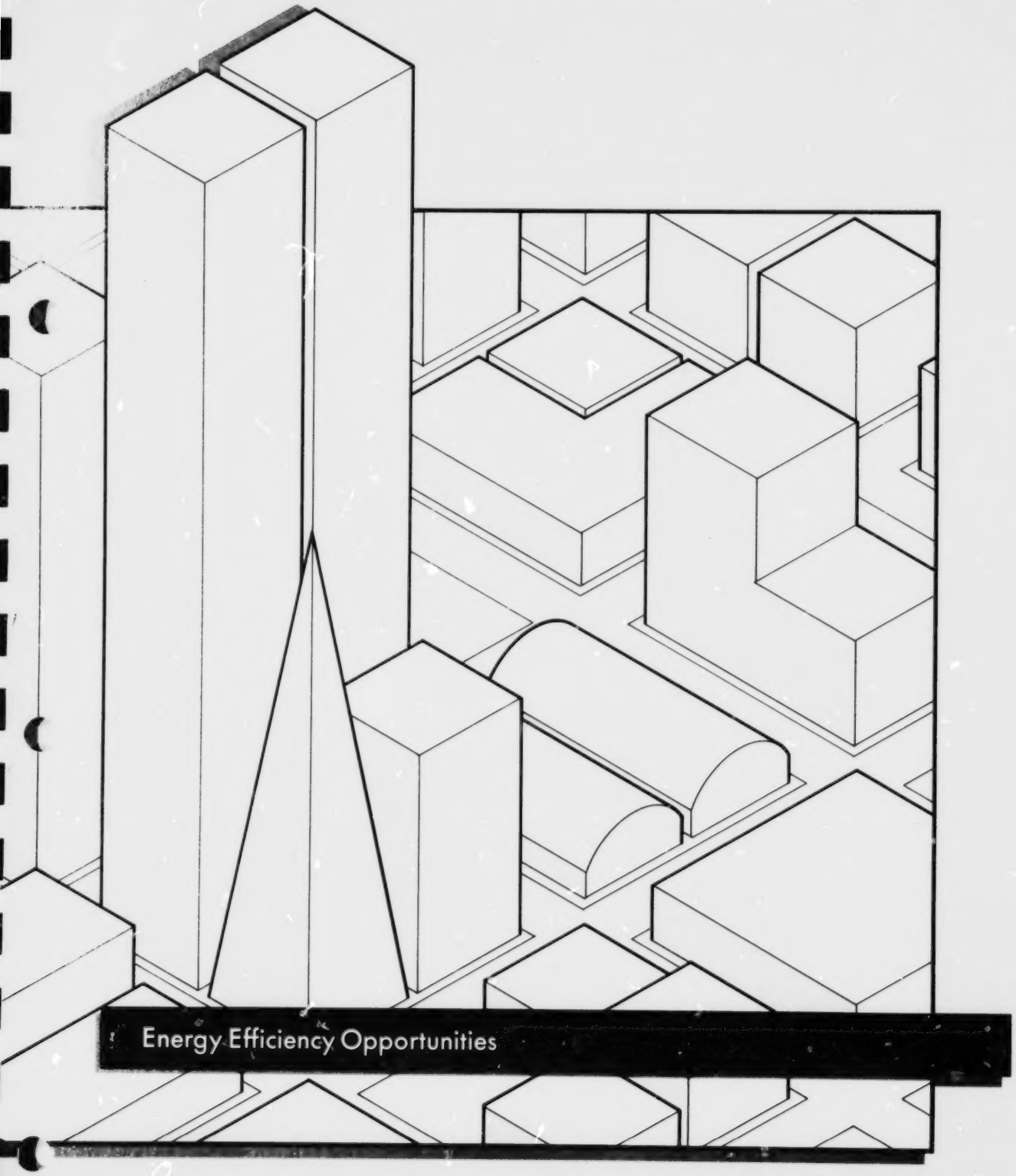
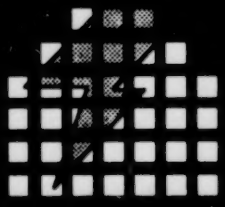
ENERGY MANAGEMENT FOR BUILDINGS AND FACILITIES



Energy Efficiency Opportunities

Ministry of Energy
Ontario

Vincent G. Kerrio
Minister



ENERGY MANAGEMENT for BUILDINGS and FACILITIES

Ministry of Energy
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Honourable Vincent G. Kerrio
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Ontario Ministry of Energy

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Introduction

Over the past ten years energy management has become a widely known applied science. During this period new measures, technologies and analytic approaches have been developed. Our understanding of energy management has developed as well. Where once it was perceived as a one-time activity, it is now seen as an on-going and essential part of building management.

We also have a better understanding of the relationship of fuel price fluctuations to energy management. While energy management made obvious sense during periods of shortage and rapidly escalating prices, we now know through detailed studies that further savings are possible even during periods of lower fuel prices. Moreover, long- range forecasts of energy supply and price indicate that it is wise to reduce consumption as much as possible while prices are relatively low.

This manual is addressed to managers and operators of publicly supported and commercial buildings in the Province of Ontario. It is intended to provide a current overview of energy management and to serve as a reference guide to energy management opportunities.

The manual is not intended as a basic text on the subject. It is assumed that the readers are familiar with building envelope and mechanical systems as they relate to energy management. The manual is generic in approach, addressing all building types. Specific information relating to specialized buildings such as health care, educational and recreation facilities will be provided in separate companion guides.

Chapter one of the manual provides an overview perspective on energy management today. Subsequent chapters deal with specific aspects of energy management such as building envelope, building operation and maintenance, heating systems, cooling systems and air handling systems. These chapters provide a brief review of the relevant issues followed by a checklist of current energy management opportunities. A separate chapter is devoted to the emerging issue of air quality as it relates to energy management. The appendices provide reference information and a bibliography.

1 Energy Management

1.1 Introduction

Initially energy management was viewed as a one-time application of conservation principles to the building envelope and mechanical systems. Experience has shown that greater savings may be obtained and sustained when energy management is considered an on-going process.

This chapter will introduce the concept of energy management as a process and outline the various elements involved in an on-going energy management process.

1.2 Energy Management Process

Energy management is not an ACTION that one performs on a building. Rather, it is a PROCESS that involves a number of key elements.

These elements include:

- an assessment of the building,
- a listing of appropriate energy conservation measures based on the assessment,
- carefully planned implementation, and
- regular review of actual energy savings.

Once initiated, energy management is an on-going process that is integrated with routine building maintenance and operation and with any subsequent changes to building occupancy, envelope or mechanical equipment.

Figure 1.1 shows in graphic form the difference between energy management as a PROJECT and as a PROCESS.

The process approach has a number of advantages:

- The best and most cost-effective measures for a particular building are selected and are implemented in the proper order.
- Monitoring energy conservation results provides feedback for improving existing energy conservation measures, for adding new measures, and for motivation.
- The useful service life of building envelope and mechanical components is extended.
- Occupant comfort and productivity is improved.
- The long-term result is a building that operates at optimum efficiency and lowest total operating cost.

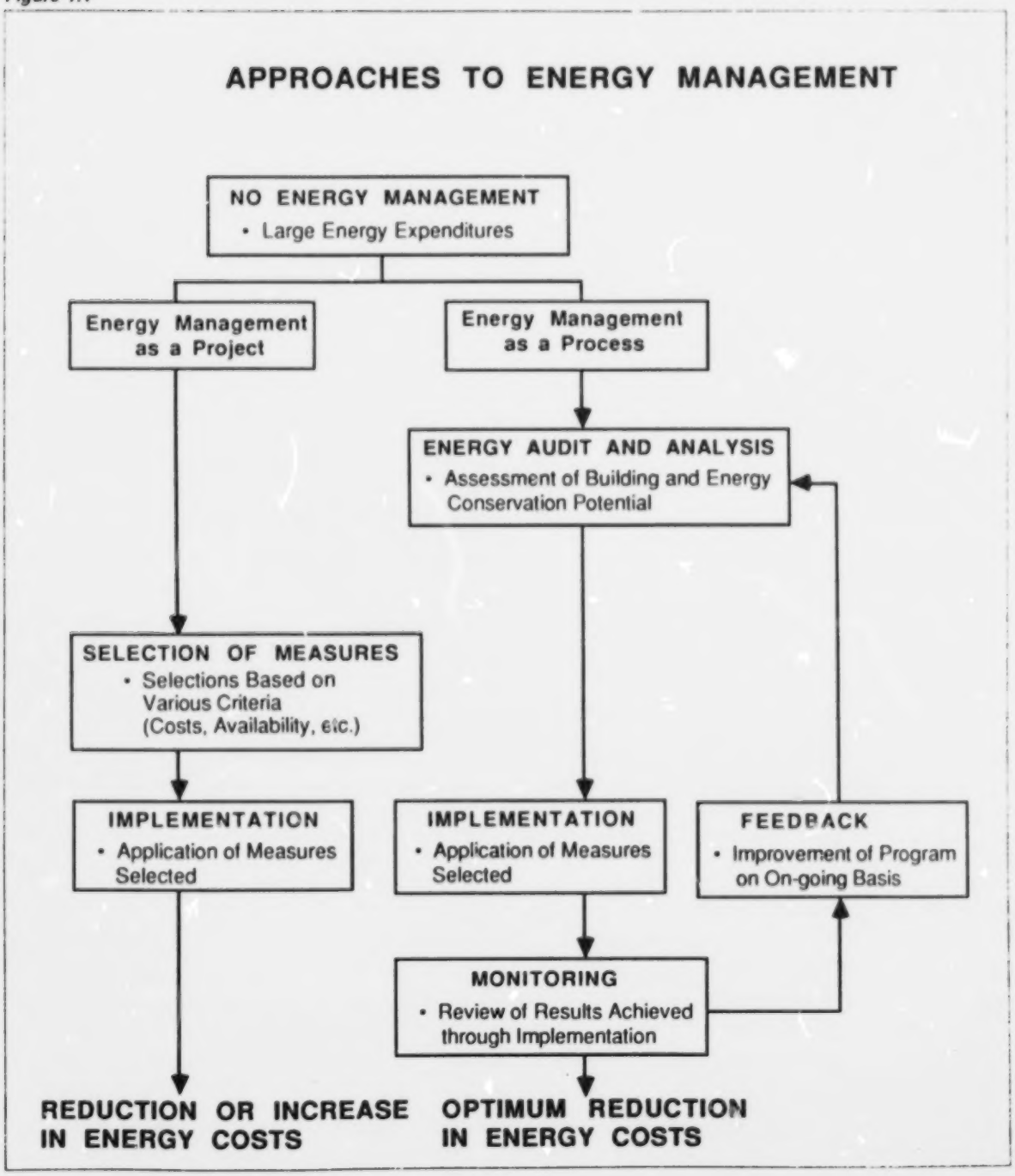
In addition, energy management as a process recognizes that buildings are not static. Occupancy changes can affect internal space allocations and patterns of building use, which can in turn affect the demands on and the performance of the mechanical system. Components of the building envelope require regular maintenance and replacement or upgrading at the end of their useful service life. These changes can also affect the demands on the mechanical system and energy usage. The mechanical system itself requires regular maintenance, and its components will eventually require upgrading or replacement. Integrating energy management activities with on-going maintenance and building upgrading provides the most cost-effective way to manage building resources.

Like any other management process, energy management requires careful planning. Time is required to analyze, plan, and co-ordinate

conservation measures. Professional consulting services may be required for complicated buildings or systems. Allocations of labour will be required for monitoring and review of program results.

The extra time involved to use the process approach to energy management is a worthwhile investment. It will ensure the best return for each building.

Figure 1.1


APPROACHES TO ENERGY MANAGEMENT
NO ENERGY MANAGEMENT
• Large Energy Expenditures
Energy Management as a Project
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ENERGY AUDIT AND ANALYSIS
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• Selections Based on Various Criteria (Costs, Availability, etc.)
IMPLEMENTATION
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IMPLEMENTATION
• Application of Measures Selected
FEEDBACK
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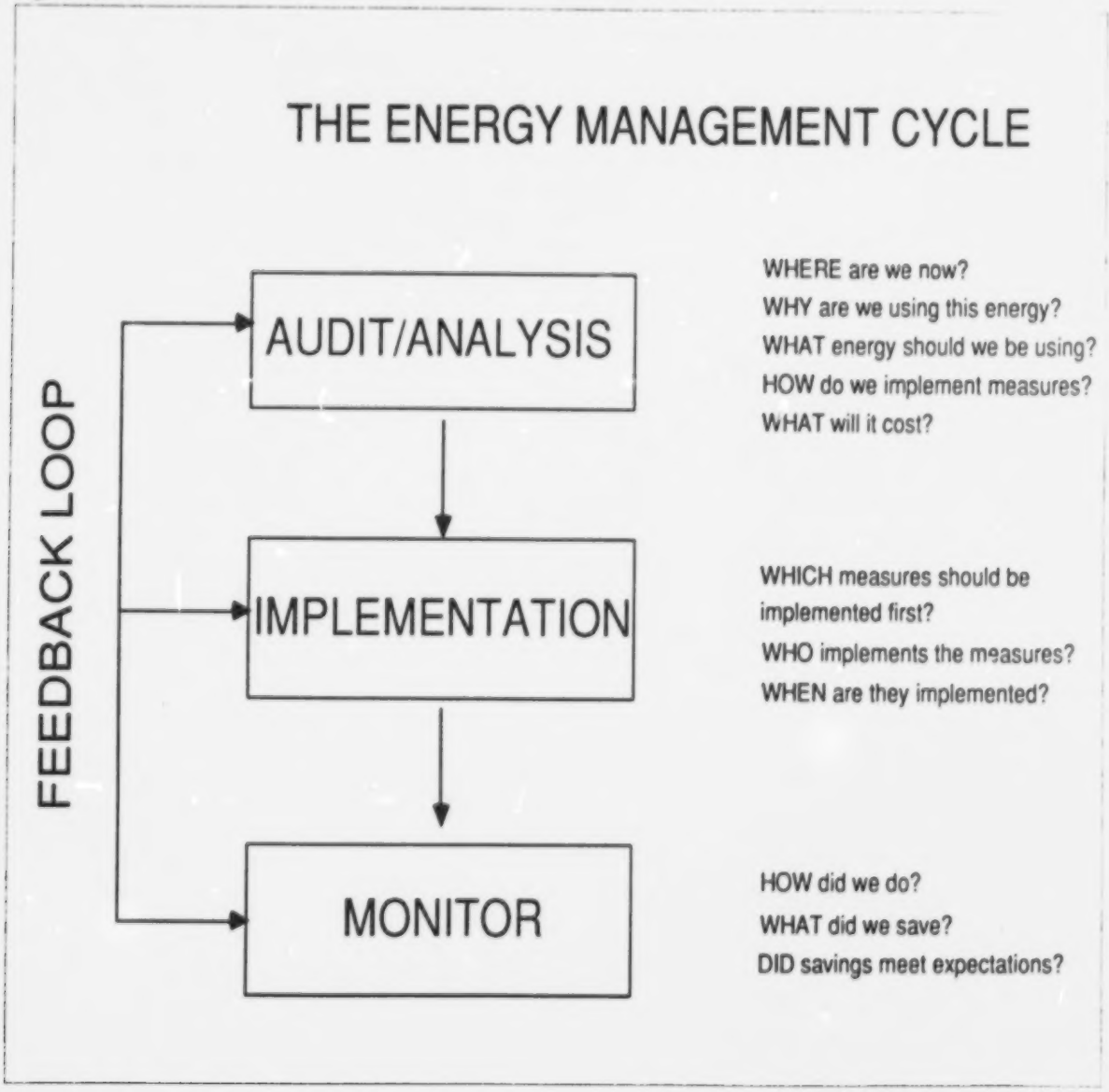
MONITORING
• Review of Results Achieved through Implementation
REDUCTION OR INCREASE IN ENERGY COSTS
OPTIMUM REDUCTION IN ENERGY COSTS

1.3 Energy Management Steps

The three major steps involved in Energy Management are:

Step 1: Energy Audit and Analysis
Step 2: Implementation
Step 3: Monitoring

Figure 1.2



Step 1: Energy Audit and Analysis

While a simple walk-through audit will often reveal many opportunities for savings, it is recommended that a full energy audit be undertaken. This will serve as the foundation of the implementation program and as a reference point for monitoring progress. A complete audit can also provide a reference point for partial studies which may be required in future years owing to major changes in building occupancy, envelope or mechanical systems.

A full ENERGY AUDIT is a complete assessment of the building and its energy use patterns. The physical characteristics of the building shell (e.g., walls, windows and doors, roof, floor, etc.) and the various electrical and mechanical systems (e.g., heating, ventilation and cooling equipment, lights, water heater, etc.) are inspected. Utility bills are reviewed to determine actual energy use. If possible, energy use is allocated to each building system separately. (See Figure 1.3 for a sample form used to record purchased energy.)

The energy audit should include a TARGET energy use. A building target is defined as the lowest annual energy use that is needed for a building or a group of buildings to provide required environmental conditions and that is attainable through current investment criteria.

The energy audit also provides the necessary information for designing an IMPLEMENTATION program. A list of energy conservation measures is developed based on the energy analysis and target energy use. The list is usually divided into no-cost housekeeping measures, low-cost maintenance and upgrading and major retrofit or upgrading projects involving considerable capital expenditure. Capital costs and estimated savings for each measure are summarized in the energy audit report.

Practical concerns such as availability of funds, staff resources, and existing maintenance and repair programs are considered when developing and planning energy management measures.

Step 2: Implementation

In addition to the building information and recommended measures from the building energy audit, many other practical concerns should be considered in the development of the implementation plan. These include:

- existing maintenance program for envelope and mechanical system;
- existing repair and upgrading program for envelope and mechanical system;
- projected plans for changes in building occupancy;
- projected plans for major repairs or renovations;
- available funds;
- available staff resources for implementation and program management.

When complete, the implementation plan will integrate these concerns with energy management measures. The result will be a practical and cost-effective program tailored to the specific building.

In most cases the implementation plan will be phased over a number of years. Generally no-cost and low-cost measures are undertaken first as these represent rapid paybacks and the savings generated can be used to finance more costly measures.

Implementation of specific energy management measures proceed according to the implementation program. Some key steps in the program are:

- allocation of capital funds and staff resources,
- obtaining estimates and selecting consultants for measures that require professional assistance,
- assigning a project manager or energy manager responsibility for program implementation and monitoring results, and
- selecting contractors and/or internal staff to implement measures.

Step 3: Monitoring:

MONITORING an energy management program is essential in order to measure results and to steer the program with progressive feedback. The simplest monitoring technique involves reviewing energy bills on a monthly and annual basis and comparing them to a previous reference year. However, a more complete monitoring program will include keeping records of factors which affect energy usage. A sample list of the components of a complete monitoring program is noted below.

- measuring energy usage and costs;
- logging building system performance through indicators such as supply air temperature and boiler efficiency;
- logging weather conditions;
- recording any additions or modifications to the building;
  recording patterns of building occupancy and use and occupant comments on comfort;
- recording any changes in occupancy patterns and use;
- recording energy management measures as they are implemented;
- logging maintenance of building equipment and systems.

Many of the data noted above will already be available through other building record-keeping operations. By including factors which affect energy use, the energy accounting process will be more meaningful. The program manager will thus be able to diagnose inconsistencies in energy use and pinpoint problem areas in building operation and in implementation of the energy management program.

PURCHASED ENERGY RECORDS

YEAR _____

OPERATING UNIT____ COST CENTRE_____ PREPARED BY_____ DATE _____

TYPE OF FUEL	PURCHASED ELECTRICITY							NATURAL GAS			FUEL OIL #2			FUEL OIL #6			COAL TYPE____			PURCHASED STEAM__psi			OTHER			TOTAL	
UNITS	kWh USED	de-mand MAX. kW	demand CHANGE	POWER adj. FACTOR	FUEL adj.	TOTAL $	MJ	MJ/m^3	$	MJ	Litres	$	MJ	GAL.	$	MJ	TONNE	$	MJ	Kg	$	MJ		$	MJ	$	MJ
COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
JAN.																											
FEB.																											
MAR.																											
1st QTR.																											
APR.																											
MAY																											
JUN																											
2nd QTR.																											
JUL.																											
AUG.																											
SEP.																											
3rd QTR.																											
OCT.																											
NOV.																											
DEC.																											
4th QTR.																											
YEAR TOTAL																											

Figure 1.3

1.4 Energy Accounting

Energy accounting is defined as the systematic tracking and analysis of energy costs and consumption in order to better manage and control energy in buildings. In energy accounting the information gathered through monitoring is used to report on the progress of the energy management program. It involves determining where energy is used, how much and why. When the factors that affect energy use are understood, then appropriate adjustments can be made to energy consumption figures. These adjustments will allow the program manager to see how well the building is performing compared to other buildings or to previous years of operation.

Many factors affect building energy use. These include:

- weather conditions at the building site;
- design, quality and condition of the building envelope;
  - insulation value of walls and roof,
  - number and size of windows,
  - quality and type of windows,
  - air leakage around windows, doors and other openings,
- building mechanical systems;
  - heating, ventilating and air conditioning systems and their operation,
  - process activities inside the building such as lighting, hot water and appliances,
  - maintenance of building equipment and systems,
  - efficiency of systems and components, and
- patterns of building occupancy and use.

No two buildings are exactly alike. Energy use factors will vary from one building to the next. As a result, each building will have a unique set of energy use characteristics. However, while energy use varies from building to building, general patterns do emerge for similar buildings.

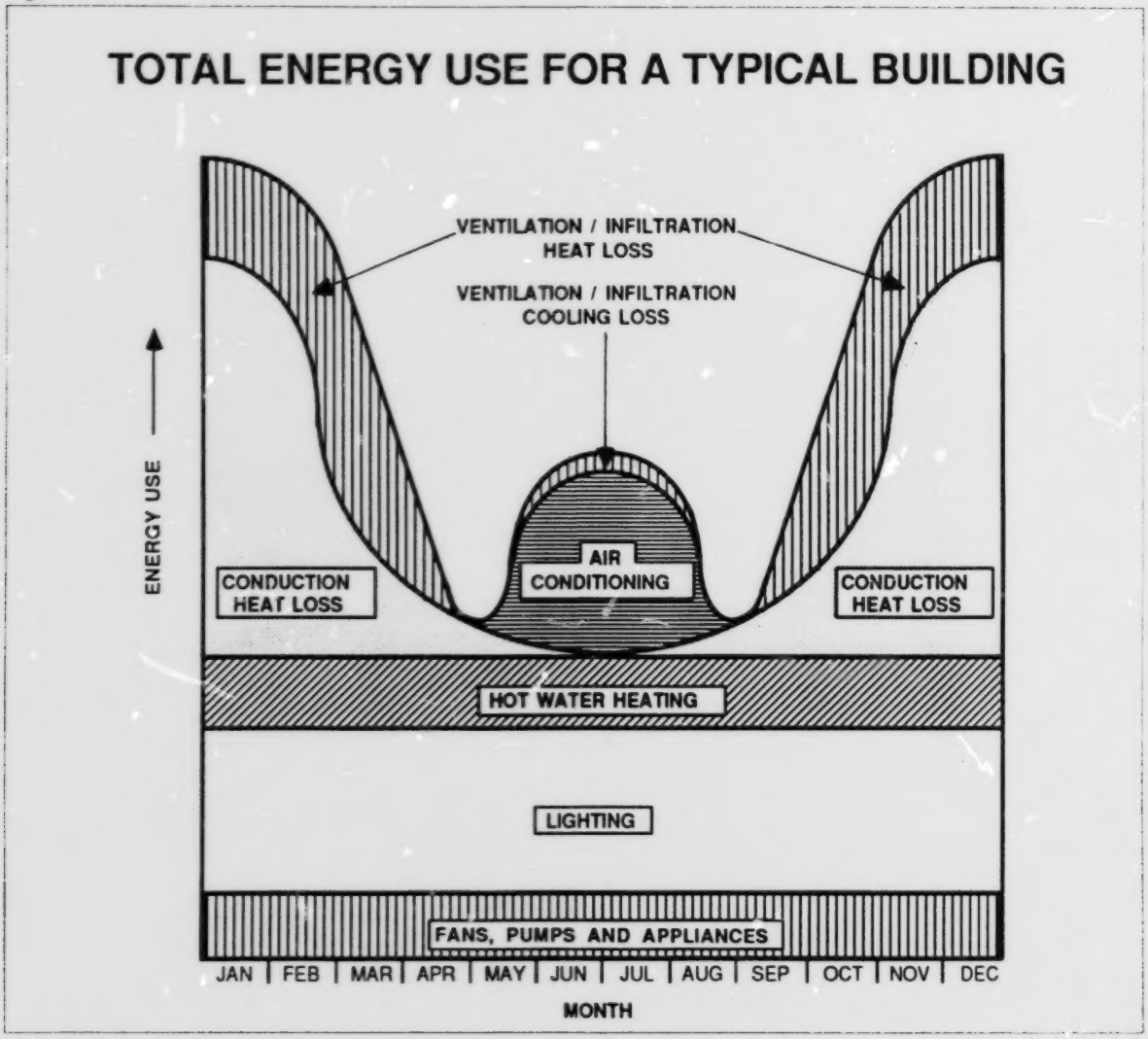
Each fuel will provide a distinct energy use pattern. The individual patterns for all fuels used can be combined to give a composite picture of total building energy use. Figure 1.4 illustrates a composite energy use pattern for a typical building.

Energy accounting requires that we compare energy use against a standard, or against a previous year of energy use. When comparing energy use, it is important to adjust for any changes in building variables. Two key principles apply here:

1. Adjustments due to an external factor (such as weather) should only be made to that portion of energy use affected by that external factor.
2. The effects of a variable must be significant enough to warrant adjustment in the energy accounting method. (Weather is a significant variable for month- to- month comparison.)

By definition, energy accounting is the systematic tracking and analysis of energy costs and consumption. Most energy accounting systems, whether computerized or manual, track basic monthly cost and usage information from utility bills. By compiling a database of historical and current energy use data, an energy accounting system can be used to analyze trends, spot potential problems, provide reports and graphs, calculate energy and dollar savings, and monitor energy management programs.

Figure 1.4



1.4.1 Benefits of Energy Accounting

A good energy accounting system can provide tangible benefits that pay for the cost of the system many times over. Some of the most attractive benefits include:

1. Verifies Monthly Invoices

Each invoice should be checked for obvious meter malfunctions, or meter reading errors before being certified for payment. By comparing this month's consumption with last month's, or the same month in a prior year, an energy accounting system will quickly define potential problems.

2. Pinpoints Problem Areas

A good energy accounting system will calculate energy consumption per unit area. This can then be used to rank buildings from best to worst, and concentrate effort for energy audits and analyses on the least efficient buildings.

3. Helps Manage Budgets
The utility costs are probably the most volatile element of operational budgets. An energy accounting system allows energy expenditures to be tracked, and constantly compares actual expenses with budgeted expenses.

4. Monitors Energy Management Programs
It is important that energy management policies and guidelines are followed. Energy accounting determines how each building uses energy, as compared with some reference energy use. This monitor provides feed-back to building managers, and fosters motivation to manage energy better.

5. Justifies Energy Conservation Investments
To compete successfully for limited funds, energy management project proposals need credible justification. An energy accounting system can be used to validate the effectiveness of completed projects and initiatives, and support requests for new projects. Cost cutting reports give senior management the documented assurance that energy management is good business.

6. Provides Reports To Senior Management
Up-to-date energy accounting reports clearly indicate how the energy management program is performing. Good energy accounting systems produce clear, concise executive summary reports for senior management.

1.4.2 Features of an Energy Accounting System

In order to account reliably for energy use and to allow proper comparisons, the following features are desirable.

1. Cost And Consumption Tracking
Systems should track both energy cost and consumption on a monthly and year-to-date basis. Often, year-to-date values are more indicative of true performance than monthly values. Alternatively, the system can calculate the costs based upon the utility rate schedule. This reduces input data quantities while providing check figures with which to identify inconsistencies in utility billing.

2. Demand Tracking
In certain locations, the demand charges from the electrical utility are the major portion of the total electrical bill. It is advisable to track demand and demand costs in those locations where the demand cost becomes significant.

3. Baseline Comparison
The system must establish a baseline or reference year, using a selected prior year for which reliable data is available. The baseline serves as a "yardstick" with which to measure current performance.

4. Normalization
The system should normalize (adjust) for differing numbers of days in the billing period before calculating performance percentages to prevent billing period variances from introducing meaningless fluctuations in reports. It should make adjustments for weather variations while recognizing that not all energy consumption is weather-related. In

addition adjustments should be made for changes in building use, occupancy or size.

5. Calculate Energy Use Index

The system should be able to convert all energy used in each building to a common unit basis (MJ/m^2 or $ekWh/ft^2$) and then calculate monthly and year-to-date values, to rank building efficiency. (See Appendix 1 for detailed information on measuring and metering energy usage.) As many new building standards are based upon unit area energy consumption, it is important to see how your buildings compare with others. You may also want to calculate energy use per person, or per unit of production, depending upon specific needs.

6. Use a Tiered Reporting System

Each manager needs only his data and his performance percentages. A one-page building summary is usually best. Likewise, senior management needs only the bottom line - a concise executive summary report. Should detailed information be required, it should be available.

1.5 Energy Use Indices

Energy accounting programs, as a rule, should be able to calculate Energy Use Indices (EUI's) for a building. These calculations can also be readily performed by hand. Figure 1.5 is an EUI Calculation Form. It summarizes the actual energy consumption of a building for one year and provides a simple calculation for finding the building's EUI — an expression of actual energy use for the whole building in equivalent kilowatt-hours per square metre per year (ekWh/m^2/yr.)

The EUI Calculation Form describes on one sheet the energy consumption for each month the building operates and for each fuel the building uses. By completing the form each year, energy use and the effect of energy conservation measures can be monitored. Completing the form for a series of buildings will provide clear and concise comparisons of annual energy use and expenditures.

Completion of the EUI Calculation Form involves several steps:

1. For each fuel that is used in the building, list monthly utility billing data (quantity of fuel and cost of fuel). Also list the reading date to allow adjustments for different billing periods. (Note: if utility data are not available on a monthly basis, proceed directly to step 2). The month-by-month breakdowns are very useful in detailing seasonal variations in energy use, but are not essential for completing the EUI Calculation Form.
2. Add the columns for fuel quantities and costs to determine annual amounts. Enter each annual amount as the appropriate "Total Per Year". If only annual utility data are available, enter annual amounts directly.
3. Add the costs for all fuels together to determine the Grand Total Energy Cost.
4. Under "Actual Energy Use", enter the annual consumption totals ("Total Per Year") for each fuel. Multiply these quantities by the conversion factor to determine actual energy use figures for each fuel. (Note. If fuel consumption data are not provided in the units shown, an alternative conversion factor must be used.) Some conversion factors are listed in the table below.

Electricity		-	3.6	MJ/kWh		
Natural Gas	=	37.0	MJ/m^3	=	10.3	kWh/m^3
	=	1,048.0	MJ/Mcf	=	291.0	kWh/Mcf
Oil #1	=	36.0	MJ/L	=	10.0	kWh/L
	=	163.8	MJ/gal	=	45.5	kWh/gal
Oil #2	=	38.0	MJ/L	=	10.6	kWh/L
	=	163.8	MJ/gal	=	48.0	kWh/gal
Oil #4	=	40.0	MJ/L	=	11.1	kWh/L
	=	182.0	MJ/gal	=	50.5	kWh/gal
Oil #6	=	42.0	MJ/L	=	11.7	kWh/L
	=	191.0	MJ/gal	=	53.2	kWh/gal
Coal	=	21.0	MJ/Kg	=	5.8	kWh/Kg
	=	9.5	MJ/lb	=	2.9	kWh/lb
Steam	=	23.0	MJ/Kg	=	6.4	kWh/Kg
	=	10.3	MJ/lb	=	2.9	kWh/lb
Propane	=	26.0	MG/L	=	7.2	kWh/L
	=	118.3	MJ/gal	=	32.8	kWh/gal

5. Calculate the EUI by dividing the actual energy use by the gross floor area.
6. After calculation of EUI's for your buildings, compare them against published standards.

Figure 1.5

EUI Calculation Form

MONTH	NATURAL GAS		PROPANE		NO. 2 FUEL OIL		ELECTRICITY	
	QUANTITY (m^3)	TOTAL COST $	QUANTITY (m^3)	TOTAL COST $	QUANTITY (LITRES)	TOTAL COST $	QUANTITY (kWh)	TOTAL COST $
1	2	3	4	5	6	7	8	9
JAN.								
FEB.								
MAR.								
APR.								
MAY								
JUN.								
JUL.								
AUG.								
SEP.								
OCT.								
NOV.								
DEC.								
TOTAL PER YEAR								

GRAND TOTAL ENERGY COST
FROM COLUMNS 3,5,7&9 ____ $

TYPE OF FUEL	ACTUAL ENERGY USE			
	CONSUMPTION	X CONVERSION FACTOR	=	ENERGY USE (kWh/yr)
NATURAL GAS		x 10.3	=	
PROPANE		x 7.2	=	
NO. 2 FUEL OIL		x 10.6	=	
ELECTRICTY		x 1.0	=	
TOTAL ENERGY		TOTAL	=	

ENERGY USE INDEX (EUI)

$$E.I. = \frac{\text{ACTUAL ENERGY USE (kWh/yr)}}{\text{GROSS FLOOR AREA } (m^2)} = \frac{\text{(kWh/yr)}}{(m^2)} = kWh/m^2/yr$$

1.6 Technical Assistance for Energy Management

Technical assistance for energy management activities is available from a number of sources:

1. publications from provincial and federal governments,
2. industry associations,
3. videotape material (public and private sector),
4. technical personnel from the provincial ministries,
5. suppliers of energy management products,
6. contractors providing energy management services, and
7. engineering and technical consultants.

All sources of technical assistance have specific advantages. A number of technical measures in this manual are marked as requiring technical assistance before implementation. In each case, the measure involves a complex array of choices for the building manager/operator. An informed decision requires detailed knowledge of the technical problem and the potential solutions.

In many cases, the technical assistance can be derived from published material or videotape material. Similarly, the building owner/operator can seek the advice of suppliers or contractors for detailed application information. A visit can be made to similar buildings where the measure has been successfully implemented. Care should be taken to ensure that more than one supplier or contractor is consulted in order to cross-reference the information provided. Similarly, more than one installation of the measure should be checked for comparison purposes. In the case of energy cost savings for measures or products, the information should be fully documented with an energy monitoring program.

An engineering consultant will be required for any measures where building design is to be changed. Ministry technical personnel could be consulted for guidance on the need for consultants on a specific project. The engineering consultant can provide technical assistance without bias towards a particular product or methodology.

An engineering consultant should not be retained solely on a low bid for services. The following factors should be considered when evaluating consultants:

1. the background and track record of the consultant's company;
2. similar projects completed by the company;
3. referrals for similar work;
4. proposed workplan for your project;
5. time frame to complete your project;
6. who will be project manager for your project/what experience;
7. who will be on the project team/what experience;
8. quality assurances for your project success;
9. understanding of the project requirements/needs; and
10. price for services and terms of payment.

Consultants should be interviewed to evaluate these factors in some detail. A written proposal of service should be requested from each consultant. References and referrals should be carefully checked. In most cases a consultant's track record is the best indication of how they will perform for your project.

1.7 Financing Options for Energy Management

Energy management programs can be financed using a number of options. In all cases, the program should contain the audit, implementation and monitoring procedures. For example, failure to provide funding and personnel for energy monitoring may result in poor follow-up and failure of energy management measures.

The financing options for energy management programs are described below.

1. Operating Funds

Many low-cost/no-cost measures can be funded from existing operating budgets. Energy is an operating expenditure, and energy cost savings can be used to purchase energy retrofits. Operating funds are not always available for energy management programs; however, when paybacks are less than one year, operating funds can be one possible financing option.

2. Capital Budgets/Government Programs

Energy management retrofit programs can be funded from capital budgets. Each ministry organization usually provides some financial assistance for retrofit projects. Application for capital funding is usually processed on a merit basis. Projects with good potential may be allocated some capital funds; however, the amount may not be enough to cover the entire project.

3. Leases

Leases can be used to purchase energy management equipment. Lease payments can be designed to be less than the projected energy cost savings. No capital funds are required for leasing agreements; however, a commitment is made to make a stream of payments for the equipment over the lease term.

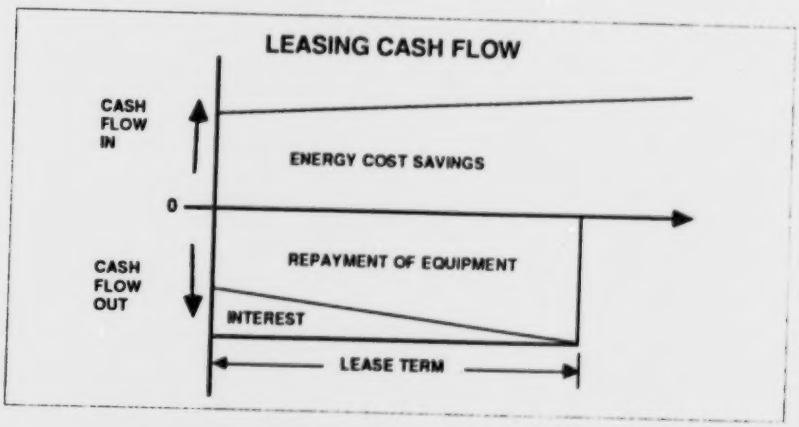


Figure 1.6

The cash flow shown in the diagram above is positive for the lease term since lease payments are less than energy cost savings. The equipment lease can be structured to provide performance obligations for the equipment supplier. Usually, the equipment supplier will guarantee that energy cost savings will exceed the lease payments.

Leases are structured as a capital lease or an operating lease. Capital leases are classified as installment purchase contracts where the equipment is being purchased on an installment basis. Ownership of

equipment passes to the building in installments. An operating lease is a service lease where the ownership of equipment remains with the lessor of the equipment. Provisions can be made in an operating lease to purchase the equipment at the end of the lease term.

4. Energy Service Agreement

An energy service agreement is a performance contract which finances the project capital cost from future energy cost savings or operating cost savings. The energy service company (ESCo) provides a turnkey package including:

- a feasibility study,
- engineering of measures,
- purchase of equipment,
- installation of equipment,
- training of personnel,
- servicing of installed equipment, and
- energy management and monitoring.

The ESCo provides all capital, manpower and expertise to complete the work in return for a share of the cost savings during some contract period. Typically the contract period runs between three years and seven years.

The three principal advantages of the energy service agreement to the building manager/operator are:

1. no capital required for project;
2. minimized risk of performance for project; and
3. technology transfer and training.

The ESCo undertakes all performance risks for the delivery of energy cost savings during the contract period. The only potential risk for the building manager/operator is the quality of the contract term relationship with the ESCo. Contract provisions should include clauses to guarantee minimum comfort levels and ventilation rates.

The energy savings are calculated with reference to a base year of energy use for the building. The reference year should be a representative year of energy use. Energy accounting for savings must address changes in the occupancy and use of the building.

There are three types of energy service agreement structure:

1. **Shared savings agreements** provide a fixed-term contract period with a defined percentage of the cost savings payable to the ESCo in each year of the contract.
2. **Loan buydown agreements** treat the retrofit investment like a loan to be paid by cost savings over the contract term. If the "loan" is repaid before the contract term expires, the agreement period will be shorter than the maximum contract period.
3. **Chauffage type agreements** provide for the ESCo to pay utility bills directly and charge the building for some percentage of reference year energy use in each year of the contract. Chauffage agreements are usually fixed-term contracts; however, the percentage payments can vary in each year of the contract.

Choosing an ESCo for an energy service agreement is similar to choosing an engineering consultant. In addition to reviewing the consultant evaluation factors outlined in Section 1.6, the following evaluation factors for ESCo's should be reviewed:

- retrofit measures to be considered for building,
- agreements completed in similar buildings,
- methods for energy accounting and experience,
- local support for servicing equipment, and
- proprietary rights of the ESCo in any equipment.

The long-term advantage of energy service agreements is based on the packaging of the energy management process. ESCo's can help to introduce the process of energy management to a building. The long-lasting results will include training and technology transfer of expertise.

1.8 Evaluating Energy Management Measures

When assessing energy management opportunities it is important to keep the following in mind:

- Evaluate the building and its mechanical systems as a whole.
- Avoid remedial measures which address the symptoms and not the cause of the problem.
- Understand the variables that can affect the meaning of the terms "low cost" and "rapid payback".
- Make use of opportunities to "piggyback" energy management measures with other work.

Once a building is complete and occupied, the building envelope, occupants and mechanical equipment function as a complete system. A change to any one of these components for the sake of energy management may affect the others adversely and may not produce the desired energy savings. For example, switching off the supply air fans while exhaust fans are still required will not save energy. Makeup air will still be required to replace the air exhausted. Without the supply air fans, the makeup air will be supplied by uncontrolled infiltration through the building envelope. This infiltration makeup air will still require heating but it will not be conditioned before it reaches occupied space and it will result in cold drafts.

Avoid the aspirin approach, which treats symptoms of energy waste and not the cause. For example, before installing heat reclaim systems ensure that energy waste at the source has been reduced to the minimum.

Evaluate the cost and payback for each measure as it relates to a particular building. What may be a low-cost measure for a large building would represent a substantial investment for a smaller operation. Similarly, the payback for the same measure can vary significantly for two identical buildings depending on the number and effectiveness of energy management measures already implemented in the buildings.

Make use of opportunities to "piggy-back" energy management measures with other planned work. This applies to all work done in the building from routine housekeeping and maintenance to major repairs, equipment replacement and renovation.

1.9 Energy Management Checklist

Process:
- Review existing management and decision-making structure as it relates to energy management.
- Check to ensure that your monitoring programs can calculate energy savings accurately.

Steps:
- Check your energy audit to ensure energy used by system is identified. Have standards of performance and acceptability been set for all chosen measures? Are these standards measurable, achievable, relevant and controllable?

Measuring:
- When converting units of measurement, double-check the factors used.

Metering:
- Accompany the utility company meter reader to verify accuracy of reading.
- Verify that peak demand needle is being fully reset each month.
- Check that rate of flow being measured by gas/water/oil/steam meters is within its range of accuracy.
- Recalibrate steam meters on a regular basis; verify that orifice plate is proper for steam pressure.

Accounting:
- Track your current energy use and cost.
- Based on your level and pattern of consumption, choose the most cost-effective utility rate.
- When comparing performance to previous years, take into account weather and billing period differences.
- Investigate utility- or government-sponsored conservation programs that can assist you financially or technically.
- Investigate other financing arrangements, for example, ESCo's, low-interest loans, etc.

EUI (Energy Use Index):
- Ensure that the area used to calculate the EUI truly represents the area in which the energy is being used.
- After calculation of EUI's for your buildings, compare against published standards.

Building Envelope 2

2.1 Introduction

The building envelope consists of the roof, floor, walls, windows, and doors – all parts of the building that enclose the interior building space and separate it from the outdoor climate.

The building envelope performs several functions. It provides:

- shelter from the elements,
- lighting (windows), and in some cases
- air change through natural ventilation (windows) and infiltration.

The envelope's success in performing these functions is dependent on the building design, quality of construction and maintenance of the envelope components.

The role of the mechanical systems and purchased energy is to make up the difference between what the envelope can provide in occupant comfort and what is required. The quality of the envelope then is a major factor in determining energy used for heating, cooling, lighting and ventilation. Improvements to the envelope can significantly reduce energy demand.

Uncontrolled air leakage through the building envelope is often associated with moisture damage to building components. An added benefit of energy management attention to the envelope is the resolution and prevention of problems affecting the service life of envelope components.

This chapter will review the causes of heat loss through the building envelope and discuss strategies for upgrading the thermal performance of the building envelope.

2.2 Envelope Heat Loss

Energy to heat interior spaces (in winter) or to cool interior spaces (in summer) is lost through heat transfer and infiltration/exfiltration.

2.2.1 Heat Transfer

Heat transfer refers to the movement of heat through walls, windows, doors, roof or floors whenever there is a difference between the exterior temperature and the interior temperature. Heat transfer occurs through three natural processes: convection, conduction and radiation.

- **Convection** is the transfer of heat by the movement of a fluid such as air. For example, cool air moving over a warmer surface picks up heat, carries it and transfers it to a cooler surface.
- **Conduction** is the transfer of heat directly through a solid (e.g. wood, brick, drywall, etc.).
- **Radiation** is the transfer of heat from a surface by electromagnetic waves.

The most important factors affecting the rate of heat transfer through the envelope are:

- the temperature difference between the inside and outside of the envelope and
- the thermal resistance value of the envelope assembly (RSI value).

The amount of heat transferred is mainly determined by the temperature difference and thermal resistance in combination with the area of the envelope.

Poor thermal performance of the envelope puts greater demand on the mechanical systems for heating and cooling. In addition, cold surfaces or excessive solar gain can create comfort problems and decrease the efficient use of the space. Building elements with poor thermal performance such as single glazed windows can be the site of condensation which can cause deterioration of surrounding finishes. Thermal weak points in the envelope can also contribute to the defacement and/or deterioration of building components.

2.2.2 Infiltration/ Exfiltration

Infiltration/exfiltration refers to the flow of air through cracks and holes in the building envelope when there is a difference between external and internal air pressures. Air normally moves from high-pressure (warm temperature) areas to low-pressure (cool temperature) areas. Three processes affect the rate and amount of infiltration/exfiltration:

Stack Effect

During cold weather, warm air rises to upper levels, where it leaks out to colder outside air (exfiltration). The air lost at the top is replaced by cold air which leaks into the building at the bottom (infiltration). This phenomenon is called "stack effect". The rate of infiltration/exfiltration depends on the height of the building, the difference between exterior and interior temperatures, and the airtightness of both the building envelope and the interior partitions. If a completely airtight barrier were placed halfway up the building, two independent stack effects would result. This is referred to as "local" stack effect.

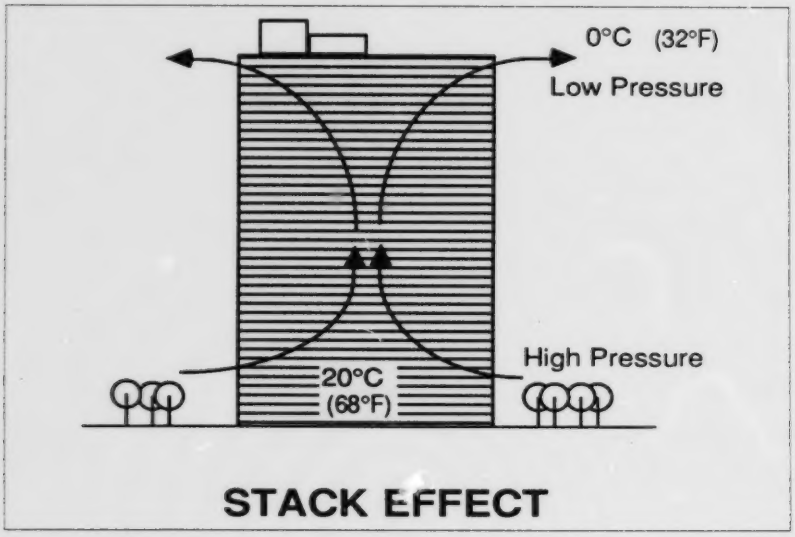


Figure 2.1

Wind Effect

Wind affects the rate of infiltration as it passes over a building by creating positive pressure on the windward side and negative pressure on the leeward side. The rate of flow depends on the geometry of the building, the strength and direction of the wind and the airtightness of the exterior walls and interior partitions.

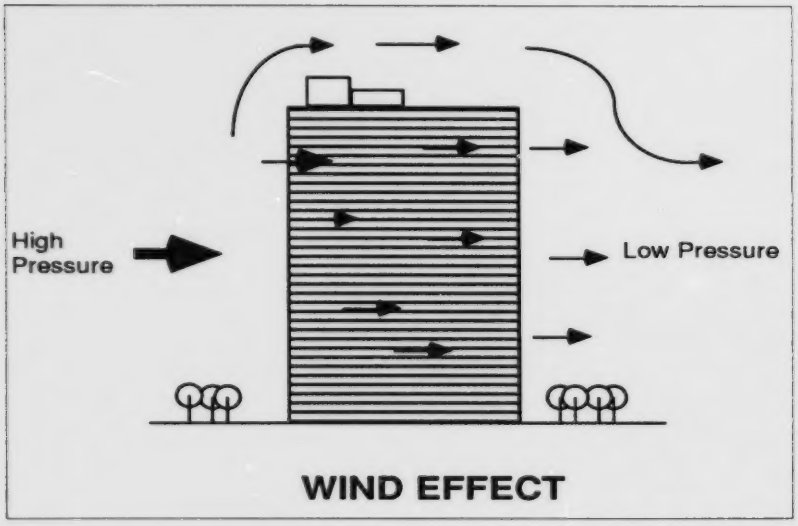


Figure 2.2

Mechanical Effect

The building mechanical systems can affect the pattern of infiltration/exfiltration through requirements for combustion and draft air and by operation of ventilation systems. In smaller buildings where there is no outside air intake for heating appliances, the requirement for combustion air can increase infiltration rates and raise the neutral pressure plane of the building. This effect can be aggravated by the use of exhaust fans until, in extreme cases, the entire building is under negative pressure and backdrafting and spillage are experienced from combustion appliances.

In larger buildings, outside combustion air is supplied directly to the heating system. However, the design and operation of the mechanical ventilation sytem can affect the pattern of building air leakage. For example, some buildings depend on natural infiltration to replace air expelled by the exhaust systems. This also raises the neutral pressure plane of the building and can result in uncomfortable drafts on the lower levels and in difficulties in opening lobby doors. In contrast, other buildings are equipped with a mechanically powered fresh-air intake and the system can be balanced so that the building is under positive rather than negative pressure. Ventilation systems should be balanced with exhaust systems to ensure optimum envelope performance.

Uncontrolled air leakage wastes heat and promotes condensation, which can accelerate deterioration of the building fabric. Common signs of moisture damage include brick spalling, efflorescence (white, chalk-like stains on the brick or block), mortar joint erosion and excessive paint peeling on exterior wood siding. If a building has spots where plaster or drywall always need repair, the cause may be air leakage and condensation, rather than a water leak.

Air leakage will also cause discomfort by disrupting the intended operation of heating, ventilating and air-conditioning systems and it can place limitations on the control of noise, fire and smoke.

2.3 Envelope Strategies

There are two basic approaches to saving energy through modifications to the building shell.

- Infiltration/exfiltration may be reduced by air sealing, air barriers, weatherstripping or adding better-fitting windows and doors.
- Thermal performance may be improved by adding insulation to the roof, walls or floor, or by adding double- or triple-glazed windows. This reduces energy lost through heat transfer.

Envelope strategies can also be examined according to their cost and to where they fit into the on-going program of building maintenance and repair.

- No-cost measures relate to housekeeping procedures and modifications to operation of the building.
- Low-cost measures are improvements that may be integrated with the regular building maintenance program.
  Major retrofit opportunities are measures that will be most cost-effective when integrated with planned modifications and improvements to the building.

2.3.1 Air Sealing First

In general, air sealing and other measures which reduce air infiltration/exfiltration should be implemented before adding insulation. There are three major reasons why air sealing should be considered first:

1. It is more cost-effective.
With rapid payback periods, air sealing measures are more cost-effective when only energy cost recovery is considered.

2. It is consistent with good building practice.
Reinsulating should never be undertaken without air sealing, and often it is difficult or impossible to air seal after insulation has been installed.

3. It prolongs the service life of building components.
Uncontrolled exfiltration causes warm, moist air to leak into wall and attic cavities where it cools and condenses, leaving moisture that can corrode or rot building materials. By stopping uncontrolled exfiltration, air sealing can prolong the useful service life of envelope components.

No matter what approach is taken, it must be remembered that every change to the envelope will affect the operation of the mechanical system. For example, air sealing can cause interior humidity levels to build up, which can in turn cause condensation on windows and other cold surfaces. To dissipate excess humidity, the mechanical system will be required to supply additional ventilation.

Air sealing will also reduce uncontrolled infiltration, which is a source of makeup air for some buildings. In these cases a powered fresh air intake will have to be added to the ventilation system in order to maintain acceptable air quality.

2.4 Air Sealing

2.4.1 Significance of Air Leakage

In the 1970's, a number of reports were issued by the National Research Council following tests carried out on:

- eight high-rise buildings (10 - 20 storeys in height),
- eleven schools of varying size, age and construction type,
- a number of supermarkets, and
- six houses of varying design, built in the 1950's.

One of the most important conclusions resulting from these tests indicated that the heat loss due to air leakage amounted to 20 to 50 % of the total building heat loss.

As air leakage is such a significant source of heat loss, it became clear that the most cost-effective retrofit procedure for the building envelope would be the filling of unintentional gaps, cracks and holes. These types of openings may have existed from the time of initial design and construction or may have developed after construction through settlement, creep and differential movement of building components.

2.4.2 Air Leakage Detection

The major areas and extent of air leakage can be determined by means of a complete building audit. The techniques used may include:

- a walk- through building audit,
- a fan-depressurization test,
- an infra-red thermographic scan, and
- smoke pencil tests.

A fan depressurizing test involves using a large fan to evacuate air from the building. While the fan is operating, it is possible to walk around the building and physically feel areas where air is leaking into the building. This type of test can also be used to quantify the extent of air leakage in the building. As a result it can provide an airtightness value for the building that can be used to compare the relative air tightness of the envelope to that of other buildings.

An infra-red thermographic scan can be used to locate sources of uncontrolled air leakage. This technique is particularly useful in diagnosing building envelope problems caused by exfiltration coupled with condensation within the wall.

The most widely used and inexpensive detection device is a smoke tester kit or "smoke pencil", which is readily available from safety supply organizations. The smoke pencil can be used to detect locations of both infiltration and exfiltration from the building interior.

2.4.3 Air Seal from the Interior

Existing buildings are usually air-sealed from the interior because of:

- convenience and cost,
- the need to create a continuous plane of airtightness on the warm side, and
- ease of monitoring and repair of the air seal.

In almost all instances it is easier and less costly to apply air sealing measures from the interior of the building. Interior work is not weather dependent, and with some training it can be incorporated into the regular maintenance duties of the building staff.

To prevent condensation that can cause damage to components within the envelope assembly, the air barrier system of the building should provide a continuous seal throughout the envelope on the warm side. This air barrier system may incorporate various materials such as drywall and window frames providing that they are joined in such a way that they create a continuous air barrier.

Once applied, an interior air seal is easier to monitor and maintain in good condition.

A complete exterior retrofit to the building envelope is another possible option. A continuous air barrier, new insulation and cladding are sometimes installed from the exterior in instances where severe deterioration of the exterior fabric has occurred and aesthetics are of concern. Professional advice will be required for retrofit measures of this type.

2.4.4 Where to Air Seal

There are many locations where the interior surface of the envelope may be punctured, permitting uncontrolled air leakage. Potential locations for air sealing measures are listed below.

Building Joints
The most significant area is often the roof/wall junction, but all joints between dissimilar materials or assemblies are potential leakage locations.

Faults in Envelope Components
Cracks in shell components such as foundation walls or interior finishing materials can permit through-wall air leakage or promote heat loss through convective air movement within the wall.

Windows and Doors
The junction of walls with window and door frames as well as the perimeter of operable windows and doors are key locations for air leakage. In addition, faults in glazing and window sash can contribute significantly to heat loss.

Mechanical Penetrations
All mechanical penetrations through the building envelope should be air sealed. Obvious locations such as cable, pipe or duct penetrations should be checked. Less obvious sites that permit air bypasses through the building include light soffits and service shafts for wiring, plumbing and garbage.

Frame Buildings
Air leakage locations will vary somewhat in frame buildings. In addition to windows, doors and mechanical penetrations, air sealing should also be undertaken at the junction of interior partitions and ceiling spaces and at the joist header/sill assembly.

Sealing all of these areas may not be cost effective. Where energy usage is the sole concern, priority should logically be assigned to the largest "holes" which can be corrected in the most economical way. Such areas as roof/wall junction, windows and doors are front-line areas where obvious and easily corrected problems will exist.

In addition, priority should be given to air leakage locations which contribute to condensation and deterioration of the building. Professional services are available, if required, to survey, audit, priorize and specify retrofit procedures and materials.

2.4.5 Air Sealing Materials

The following materials are generally low in cost and easily installed. They are used for most readily accessible air sealing locations:

1. Sealants: caulking materials, mastics, coating etc.
2. Weatherstripping: gaskets, packing etc.
3. Foams: single and two-component polyurethane

In addition to the above, rigid-sheet materials such as drywall, plywood or metal and flexible-sheet materials such as polyurethane, felts and woven fabrics are sometimes used. Their application is limited to special situations such as large areas or porous surfaces that must be covered or blocked. Each of the air sealing materials are discussed in greater detail below.

1. Sealants
Apart from the usual considerations relating to these products, i.e. durability, colour, ease of use, economics, paintability, etc. a primary concern is odour. Most sealants contain solvents which will smell when freshly applied but which will fade fairly quickly. Some will not. Some clear materials will yellow with aging. For most air sealing applications – to avoid colour matching problems – clear, paintable products which are stipulated by the manufacturer as suitable for interior use are desirable. For some applications, e.g. large cracks, sealants must be used together with "backer rods".

2. Weatherstripping
Durability is a primary consideration with steel and commercial doors. Experience has shown that heavy-duty V-seal type products installed on the jamb rather than compression-type materials mounted on the stop will last longer and stay tight even when doors warp. Door bottom seals should be installed on front and rear faces of doors and checked every year.

Weatherstripping systems are available for all types of windows, and tightening windows is usually cost-effective. Replacement or installation of extra glazing often cannot be justified by fuel savings alone. Replacement pile, a whole variety of plastic extrusions, in-situ gasket-forming and closed-cell rubber and plastic foam products can be used, in combination, to upgrade existing windows.

3. Foams

Larger gaps and holes such as roof/wall intersections, baseboards, pipe and duct penetrations are easily and rapidly sealed using polyurethane foam. Polyurethane will break down under direct sunlight and must be adequately protected. Care should be taken to comply with local and provincial building code requirements, and most applications will require contractor skills.

2.5 Insulation

2.5.1 Benefits

Upgrading the thermal performance of the building envelope can lower demand for heating and cooling. It can also improve occupant comfort and use of space by eliminating uncomfortable drafts and cold spots. Energy conservation measures may also provide effective solutions to serious building damage by correcting thermal weak points that can cause deterioration of building components.

Many energy conservation measures applicable to the building shell are expensive and difficult to justify if assessed independently and only in terms of energy costs and benefits. However, major retrofit to the building envelope can be very cost-effective when the energy component costs are "piggy-backed" onto other scheduled work.

Opportunities for major envelope upgrading include:

- scheduled replacement of building components such as roofing or window sash;
- major repair to the envelope because of damage to building components; and
- major renovation or building "facelift".

2.5.2 Audit before Action

A complete energy audit of the building will present a "thermal picture" of the envelope. This will indicate areas of greatest heat loss and cooling load. The thermal picture will be determined by the size and shape of the building, its age and type of construction. In assessing opportunities for envelope upgrading several factors should be considered:

- the condition of the envelope components;
  - any areas requiring extensive repair and/or replacement;
- projected plans for the building, i.e. renovations;
- considerations of occupancy use such as:
  - requirements for daylighting, or
  - sources of excess humidity such as swimming pools; and
- heritage aspects of the building.

2.5.3 Planning

Each part of the building envelope offers unique opportunities and constraints regarding thermal upgrading. In considering the various opportunities it is important to remember that a key requirement in effective envelope design is the provision of an adequate vapour barrier and a continuous air barrier. Some of the typical areas for thermal upgrading are described below.

Foundations

Insulating foundations is generally only advisable for smaller buildings or complexes where the basement is heated. Reinsulation is preferably done on the exterior, and with this approach it can be effectively combined with waterproofing of the foundation. If necessary, perimeter drainage systems can also be added or upgraded at the same time.

Walls

Exterior retrofit can be combined with a building facelift and offers the most practical approach to insulating walls as it is easier to provide a new continuous air barrier from the exterior. For example, uninsulated low-rise commercial buildings of unit masonry can benefit from exterior application of insulation, air barrier and new siding.

Upgrading the walls also provides an opportunity to resize the window area up or down to better suit thermal and lighting requirements. The window downsizing option has been employed successfully in older school buildings, while new windows have been installed in some modern schools that were originally designed with 100% artificial lighting.

Windows

Some options for window retrofit are noted below:

- replacement of window unit (frame and sash);
- sash replacement;
- upgrading of sash on site by adding an additional pane of glass;
- addition of interior or exterior storms; and
- addition of tinted glazing, interior shades or exterior shading devices to reduce cooling load.

Even where total wall retrofit is not undertaken windows may be downsized by adding a new unit that combines a smaller window with a curtain wall infill panel.

Attics and Roofs

For residential buildings with sloped roofs, attic insulation is a relatively simple and effective solution. Care must be taken to ensure that a vapour barrier is provided on the warm side of the insulation and that a continuous air barrier is installed.

For large, flat-roofed buildings retrofit is most easily undertaken when the roof membrane is being repaired or replaced.

2.6 Envelope Checklist

This section provides a quick review of the major opportunities for thermal upgrading of the building envelope. The numbered sections below correspond to the numbered areas identified in figure 2.3.

Foundations

1. Air-seal cracks and faults in foundation wall and mechanical penetrations. (For frame buildings, air seal also at joist header/sill assembly.)

2. Insulate bare foundation walls when basement area is heated.

Walls

3. Air-seal building joints such as:
- roof/wall junctions (including roof level changes),
- building addition junctions,
- columns in walls,
- floor/wall junctions,
- beam/truss penetrations,
- mortar joints,
- panel joints,
- joints between dissimilar materials,
- soffits, and
- expansion joints.

In frame buildings additional areas for sealing include:
- baseboards,
- interior partitions and ceiling spaces,
- attic penetrations, and
- joist header/sill assembly.

4. Air-seal faults and cracks in envelope components.

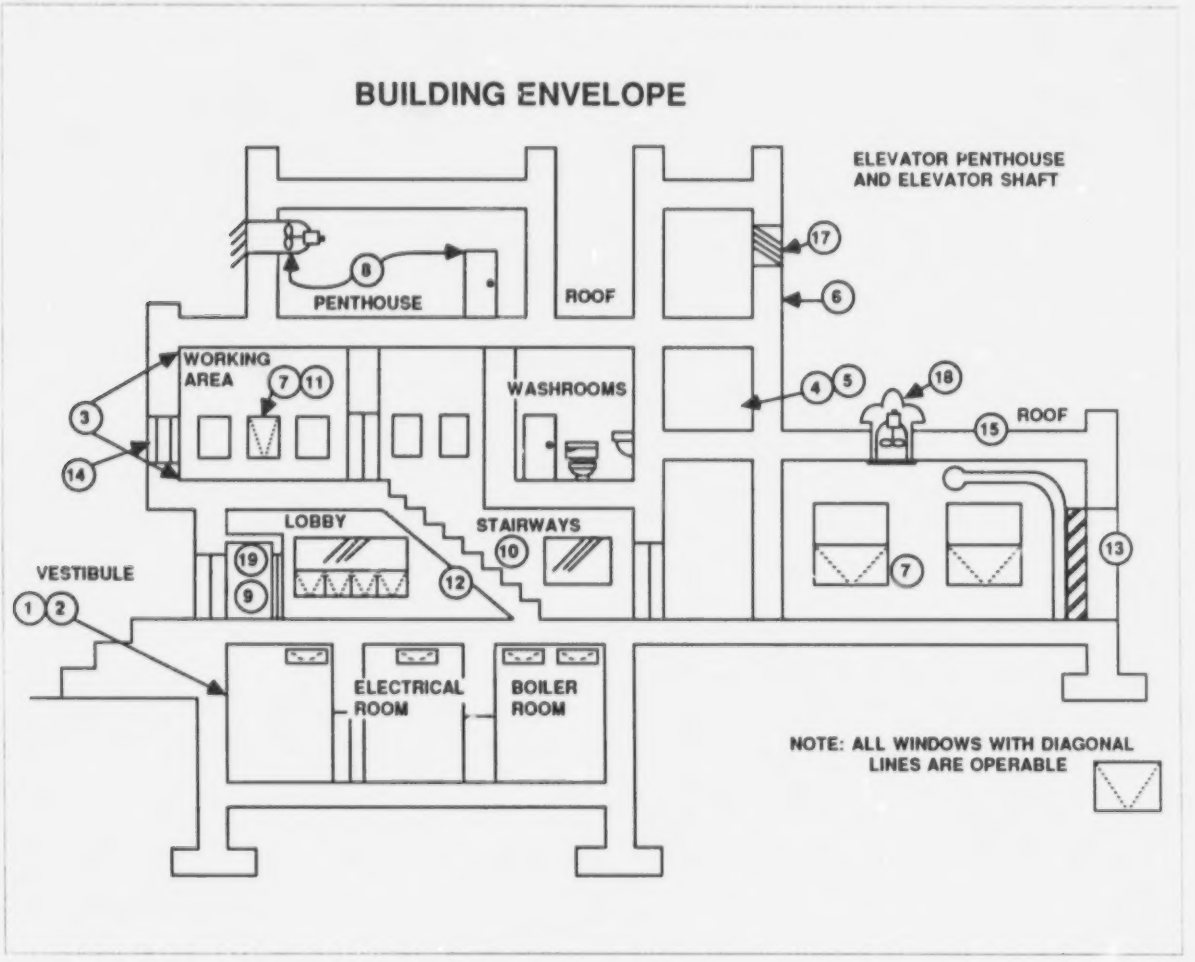
5. Air-seal mechanical penetrations such as:
- cable, pipe, duct and conduit penetrations;
- electrical receptacles and switches;
- furnace stack and vent stack penetrations;
- furnace room perimeters and doors where furnace has own fresh air supply ducted into room;
- mechanical louvres – air supply and exhaust, and smoke dampers in elevator shafts and stairwells;
- service shafts for wiring, plumbing and garbage; and
- soffits and recessed light therein.

6. Retrofit walls with insulation, air barrier and vapour barrier.

Windows and Doors

7. Keep windows closed during the heating season and, in air-conditioned buildings, during the cooling season as well. When occupants open windows during the heating season make use of the following measures.
- Find methods of reducing overheating in working areas by:
  - installing shades or reflecting films;

Figure 2.3



- improving heating system temperature control; and/or
- increasing ventilation rates.

- Organize awareness program promoting the closing of windows at the end of each working day.
- Reach agreement with housekeeping personnel to close windows and leave reminder at working station.

8. Reduce exfiltration at top of building; all openings at top of building must be airtight.

- Air seal doors and windows.
- Exhaust fans over 0.1 m^2 (12 sq in) in area should have motorized dampers.

Note: When penthouse must be vented because of combustion equipment, interior doors leading to penthouse must be made airtight.

9. Reduce infiltration at ground level.
- Replace weatherstripping of main entry as soon as worn or damaged.
- When exterior doors are difficult to keep airtight, install weatherstripping on interior doors of vestibule.
- Adjust operation of door closers (slow operation increases air infiltration rate).
- Adjust vestibule size and length to minimize occasions where exterior and interior doors are opened simultaneously.

10. Stairways

Weatherstrip door openings from stairwells and ensure stairwell smoke fans have tight closing dampers which meet local code requirements.

11. Reduce infiltration around windows. Operable windows are made airtight by:
- replacing poor weatherstripping;
- adjusting poorly fitted window panels; and
- replacing defective caulking material around window frames, under window sills etc.

12. In lobbies and circulating areas, operable windows should be made airtight during the heating season with removable caulking material installed on the interior side of windows (not applicable when caulking material can be tampered with).

13. Improve garage doors.
- Avoid use of garage door for pedestrians only.
- Install heavy-duty weatherstripping and fill in door sill to eliminate crack under door or driving gutters.
- Limit openings of door to the height of the tallest vehicle and add flexible side curtains to reduce width.
- Adjust time of opening to minimum requirement for safe use of door (approximately 20 seconds).
- If door is opened frequently (100 openings/week or more), consider adding magnetic loops in floor to control opening and closing times.
- When two doors are located at opposite ends of garage, install control to prevent simultaneous opening of both doors.

14. Upgrade windows by replacement, by on-site conversion to double glazing or by the addition of interior storms and/or shading devices. Also consider downsizing of windows where appropriate and block and insulate unneeded windows.

Roofs

15. Reduce heat losses of unvented flat roof by improving insulation when roof is being resurfaced.

16. Reduce heat losses of vented roof by retrofitting with insulation and appropriate vapour barrier and air barrier. (Not illustrated.)

Mechanical Systems

17. Elevator shaft and penthouse
Install operable smoke dampers on openings at top of elevator shaft to suit local code requirements. Set thermostat for elevator room temperature above building space temperature to avoid continuous operation of elevator exhaust fan in winter months.

18. Exhaust fans
Install backdraft dampers to prevent escape of warm building air during fan shutdown.

19. Air balance building
Building fan systems should be checked for air balance to ensure building areas are not under excessive positive or negative pressure. Corrective actions can be taken by adjusting supply or exhaust air volumes in building systems. Consult an expert if necessary.

Operation and Maintenance 3

3.1 Introduction

A thorough and well-managed maintenance program will directly contribute to reducing energy costs. Equipment which is well-maintained operates more efficiently and consumes less energy.

If maintenance of heating, cooling, ventilating or electrical systems is neglected, costs will increase in the long term. This includes: the cost of equipment downtime, emergency repair costs and the increased energy cost to operate the equipment. Energy costs will alsc increase owing to poor operating efficiencies resulting from neglect.

This chapter provides an overview of how good operational and maintenance procedures can complement a well-designed energy management program. Specifically, this chapter looks at operation and maintenance as they relate to the following systems:

- Heating
- Cooling
- Ventilation
- Water treatment
- Lighting

This chapter provides a background for the general operational and maintenance issues that affect energy use and that are good building management practice. Subsequent chapters will examine measures that can further improve energy performance.

3.2 Monitoring and Operational Logs

Energy management must become part of daily operations to be effective. All operating procedures should be energy efficient.

Energy use monitoring helps direct facility management and identify potential problem areas before they become serious. Monitoring should not be limited to energy use. It also means keeping track of general building operations and maintenance, and monitoring systems. A building manager must blend his knowledge of the building, its systems and its energy consumption to manage energy effectively .

Operations logs and well-documented operating procedures are an essential ingredient of energy management. Logs and procedures should be developed separately for each building.

Standard operating procedures relate to general maintenance and inspection and include specific means for really efficient building operation.

Keeping operational logs is one activity that is part of the standard operating procedure for a building. Operating logs perform several functions. They

- provide a permanent historical record of system performance.
- ensure that systems are inspected frequently.
- identify problems by providing historical records of changes in operation and/or energy performance.
- provide a base for evaluating new energy efficient measures and their cost effectiveness.

Operating logs are not necessary for every piece of equipment in a building. In many cases, regular maintenance routines are sufficient for operating log purposes. For large equipment, operating log sheets should be designed to record important information. Operators should understand the significance of any readings taken. Figure 3.1 shows an example of an Operating Log Sheet for an air-handling system. Log sheets should show the date, time of entry, operating status, operating parameters such as temperatures, pressures, running hours, (etc.), as applicable, as well as comments, entries on work performed and the name or initials of the recording person .

Figure 3.1

OPERATING LOG SHEET **SHEET NO: _____**

AIR-HANDLING SYSTEMS

SUPPLY FAN	DISCHARGE AIR TEMP. °F	MIXED AIR TEMP. °F	RETURN AIR TEMP. °F	FILTER* RESISTANCE	SPRAY PUMP ON/OFF	DATE	BY

*INDICATE DATE OF FILTER CHANGE

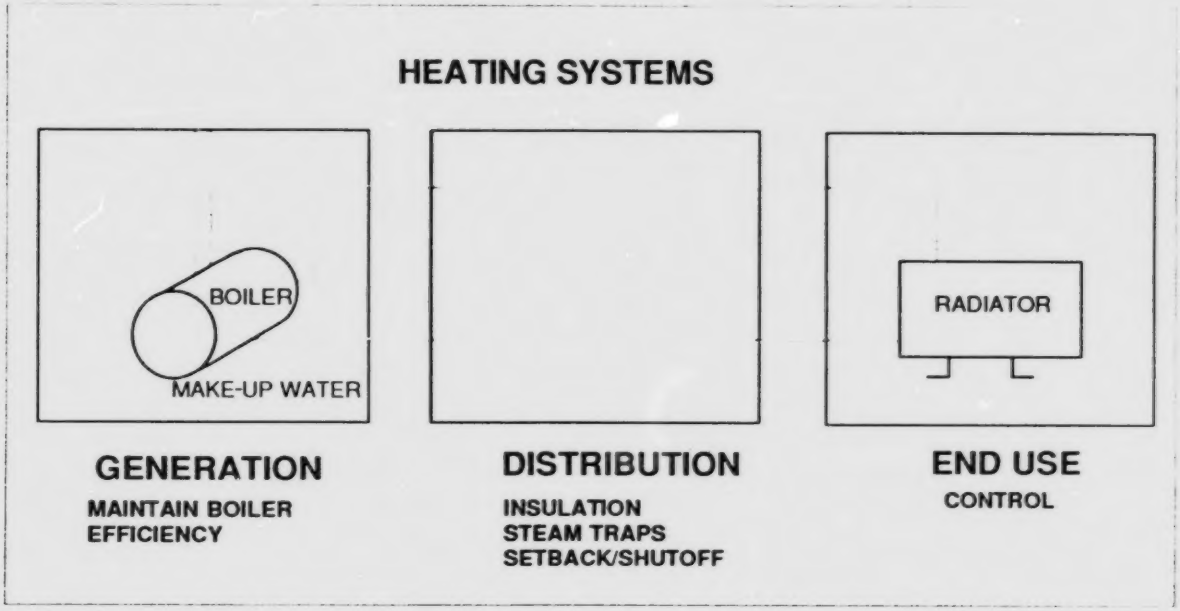
3.3 Heating System Maintenance and Operation

Heating systems are made up of three principal components:

- supply equipment (e.g. boiler);
- distribution equipment (e.g. supply and return piping); and
- end use equipment (e.g. heaters and associated controls).

These components are shown in Figure 3.2.

Figure 3.2



Regular maintenance is critical for all three components to ensure energy-efficient operation. For example, lack of regular maintenance can result in inefficient boiler operation, excessive heat losses in the heating distribution system, and poor operation and control of space heating equipment.

3.3.1 Boilers

Boiler efficiency is indicated directly from temperature and composition of flue gases. The latter indicates the air/fuel ratio at the burner, which is the most important parameter affecting combustion efficiency.

Provision of Combustion Air

Efficiency of a boiler can often be negatively affected by improper adjustment of combustion air to the burner. A drop in efficiency will tend to be more pronounced for deficient air rather than for excess air operation.

A boiler operation with deficient combustion air is undesirable because:

- combustion effiency is reduced;
- sooting affects heat transfer efficiency; and
- incomplete venting or backdrafting of the toxic and potentially explosive flue gases may result.

Boiler operators often run their boilers with a high level of excess air to ensure that the problems outlined above do not occur.

If not due to intentional operation, reduction in boiler efficiency due to excess air can be caused by many factors. The system operator should be aware of these factors and should be prepared to make regular adjustments to the boiler equipment to compensate for excess air. Factors related to excess air are listed below.

- The burner control system may not be properly adjusted.
- A change in the density of boiler room air as a result of outside temperature, pressure and/or relative humidity may result in an excess air condition.
- Worn linkage may cause "slack" in the combustion control systems.
- The burner requires maintenance.
- Fuel composition or grade has been varied without subsequent adjustment of the burner.
- There is improper control of viscosity. Viscosity can be controlled by regulating the temperature of the fuel oil in the storage tank (applies only to No. 6 heating oil).
- There is improper adjustment or malfunctioning of the atomizing control for supply of steam or air to oil burners.

Again, constant monitoring, in conjunction with regular adjustment, will allow the boiler operator to maintain optimum system efficiency.

It is worthwhile to consider buying equipment to monitor combustion efficiency. Available products range from inexpensive manual (chemical) testing equipment to sophisticated electronic monitors. Purchase equipment according to the size of your boiler(s) and your heating budget. For very large boiler systems, consider installing permanent monitoring systems for instantaneous readouts.

Boiler Blowdown Control

Maintaining boiler water quality is essential to maintaining a high system efficiency. In the generation of steam in a boiler, certain impurities (solids) in the water must be purged from the system on a continual basis via an adjustable blowdown valve. Proper adjustment of the blowdown valve must be maintained at all times.

If there is a continual demand for boiler water makeup, it may also be an indicator of steam leaks, failed steam traps, excessive venting or condensate dumping, all of which reduce heating system efficiency.

Blowdown requirements are increased as the amount of make-up water brought into the system increases.

If the blowdown valve is adjusted to allow insufficient blowdown, a buildup of sludge in the boiler can result, reducing heat transfer and general system efficiency.

If the blowdown is adjusted to flush more water than is actually necessary, heat will be lost to the sewer. More boiler make-up water and boiler chemicals will have to be added to the system.

Consult a boiler water treatment expert to determine the optimum composition of the boiler water for your system. Monitor the percentage of solids in the blowdown and any other applicable water quality parameters. This will ensure that optimal water quality is maintained and the requirement for blowdown water make-up is as low as possible.

3.3.2 Maintenance of Distribution System Piping

Energy losses in the heating system can be minimized by ensuring the regular maintenance of distribution piping. Regular maintenance includes an inventory of the system components and documentation of their condition.

In steam plants, steam trap maintenance is a primary step in reducing system losses. Malfunctioning steam traps can account for substantial energy wastage. Although traps may fail for a variety of reasons, problems in the steam system should also be considered, especially if failure frequency is high and recurs in the same locations. A few causes are: dirt, corrosion, water hammer and freezing.

3.3.3 End-use Equipment

End-use equipment in heating systems includes steam and hot water radiators, and heating coils in ventilation units. Conditions which result in excessive energy use in these components include valves which leak or are stuck open and faulty controls. These conditions are often associated with comfort problems in the space which is heated. Proper maintenance will avoid excessive energy use by end-use equipment.

3.4 Cooling System Maintenance and Operation

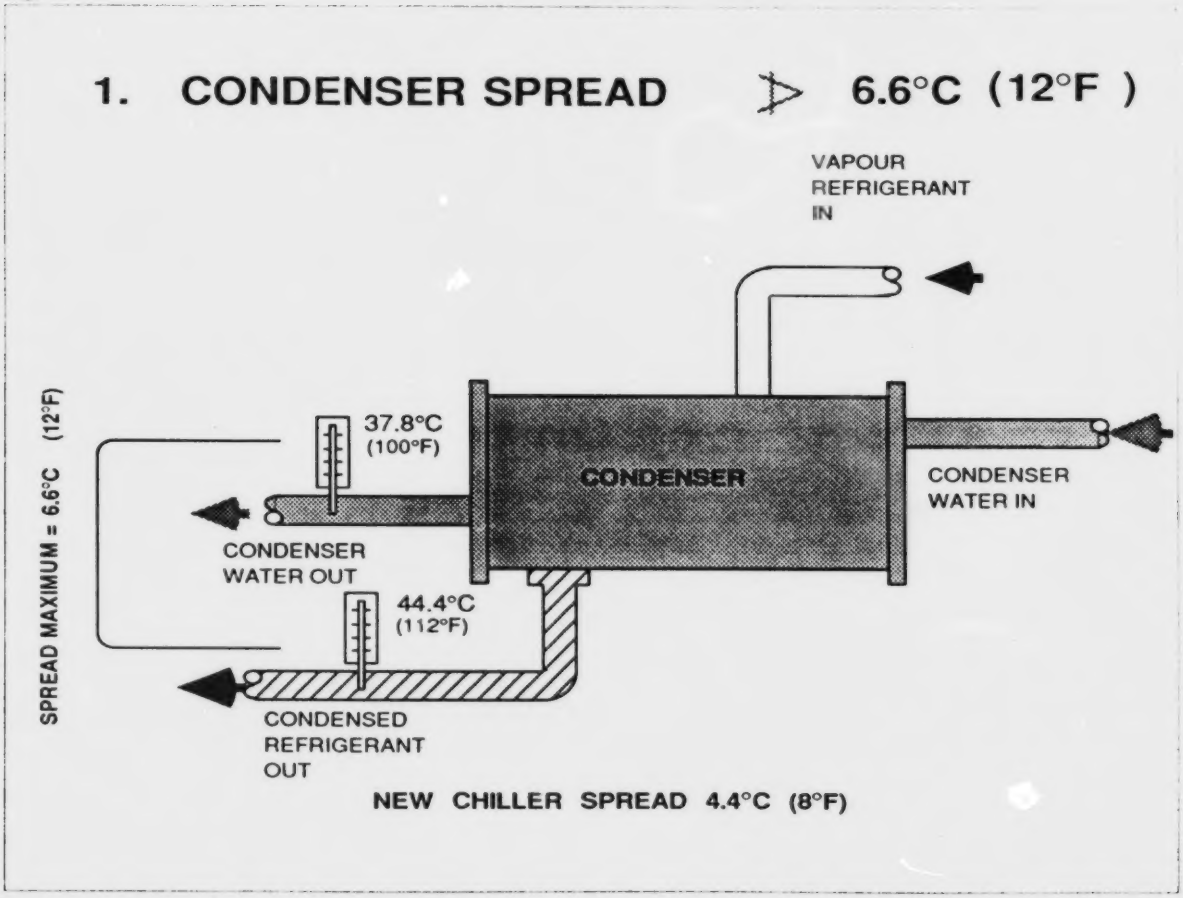
All air conditioning equipment requires regular, planned maintenance to ensure energy efficient operation. Cooling system maintenance should include periodic inspection of cooling coils (chilled water or direct expansion) for icing or dirt accumulation on the coil. Both will reduce heat transfer rates, reduce airflow to the space, make it difficult to maintain comfort and waste energy. Cooling system valves and controls should also be inspected periodically to ensure efficient system operation.

Central Chillers

For central chillers, monitoring various temperatures at the chiller provides important information for maintaining energy efficient operation and identifying maintenance problems. Figures 3.3 to 3.5 show the important temperatures to be monitored and what they mean, as well as desirable temperatures for a chiller operating at full load.

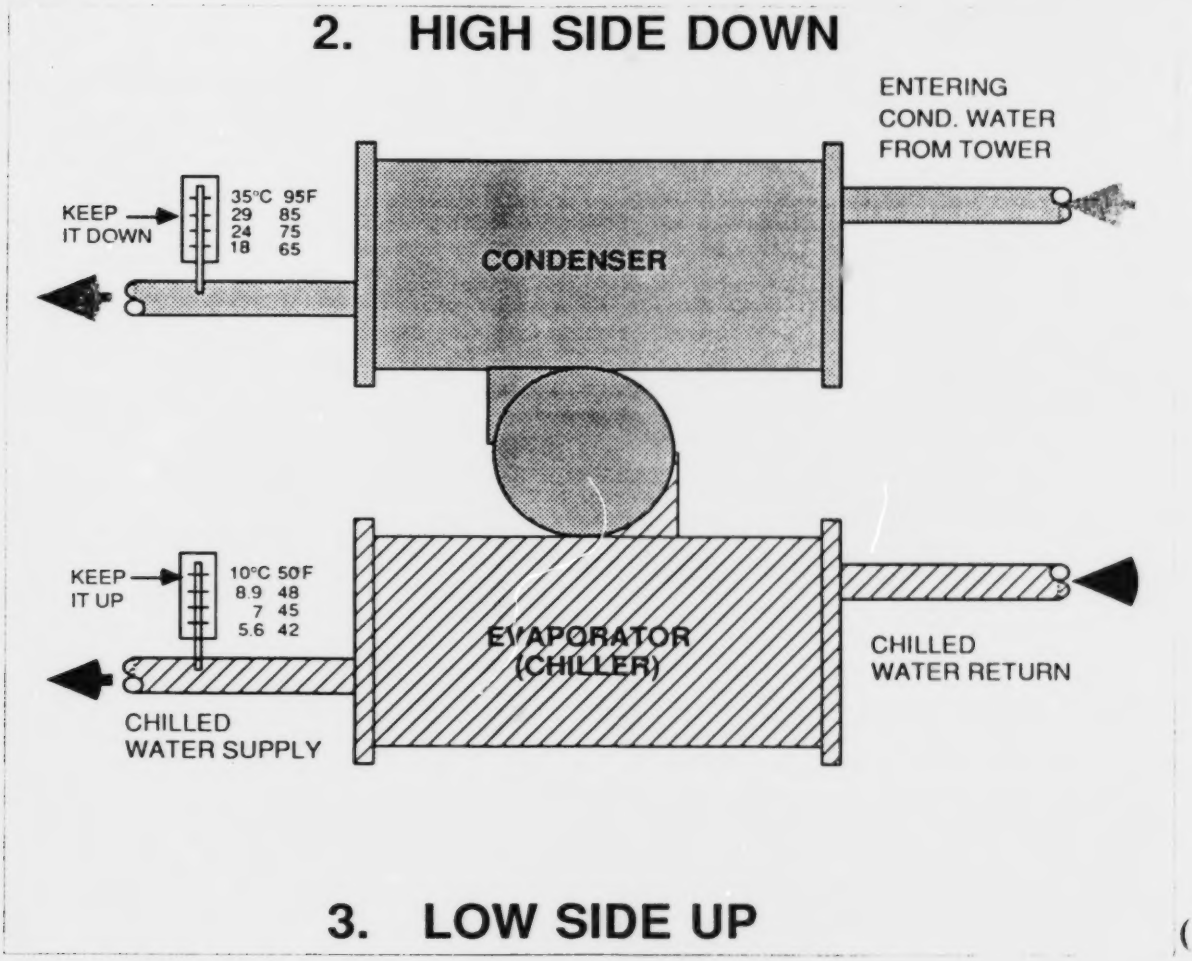
For energy-efficient operation, the temperature difference between the condensed refrigerant and condensed water should be no more than 6.6°C (12°F) or 4.4°C (8°F) for new chillers.

Figure 3.3



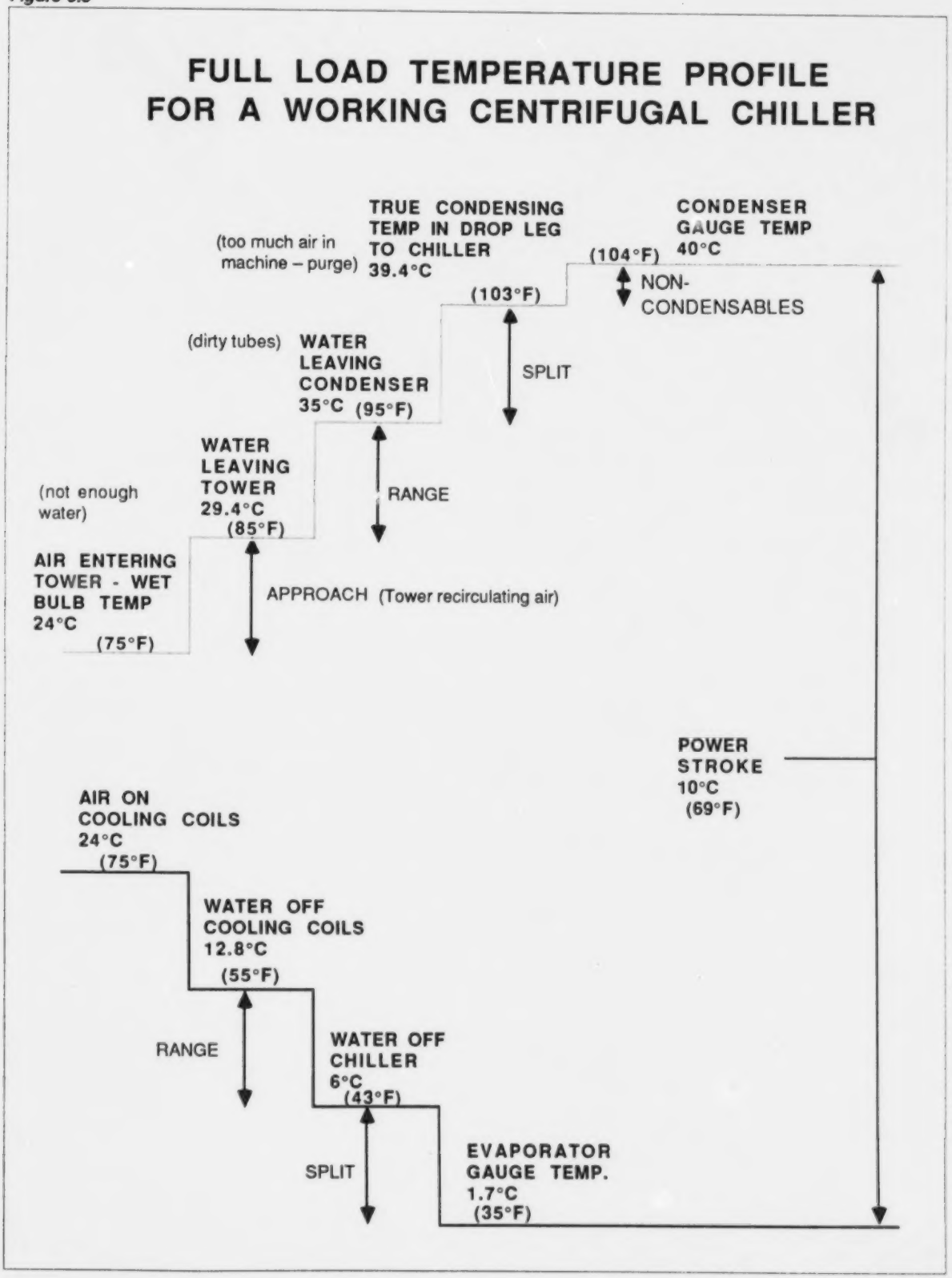
The temperature of water leaving the condenser should be kept as low as possible and the chilled water supply temperature as high as possible.

Figure 3.4



Other temperature readings will tell when heat transfer surfaces are dirty and should be cleaned, or when there is too much air or water in the refrigerant and the chiller should be purged. These conditions reduce chiller efficiency and incur higher than necessary energy costs.

Figure 3.5


FULL LOAD TEMPERATURE PROFILE
FOR A WORKING CENTRIFUGAL CHILLER
TRUE CONDENSING TEMP IN DROP LEG TO CHILLER 39.4°C
(too much air in machine – purge)
CONDENSER GAUGE TEMP 40°C
(104°F)
NON-CONDENSABLES
(103°F)
SPLIT
(dirty tubes)
WATER LEAVING CONDENSER 35°C (95°F)
RANGE
WATER LEAVING TOWER 29.4°C (85°F)
(not enough water)
AIR ENTERING TOWER - WET BULB TEMP 24°C (75°F)
APPROACH (Tower recirculating air)
POWER STROKE 10°C (69°F)
AIR ON COOLING COILS 24°C (75°F)
WATER OFF COOLING COILS 12.8°C (55°F)
RANGE
WATER OFF CHILLER 6°C (43°F)
SPLIT
EVAPORATOR GAUGE TEMP. 1.7°C (35°F)

3.5 Ventilation System Maintenance and Operation

Ventilation systems can be large energy users and energy wasters – both directly and indirectly. Energy is used directly in operating fans. Indirect energy use takes place in heating, cooling and/or humidifying the fresh air brought in from outside.

This indirect energy use can be one of the largest energy loads in a building. It tends to be overlooked because the energy use is not obvious.

3.5.1 Air Inlet Dampers

In southern Ontario, every L/s (2 cfm) of outside air brought into the building on a continuous basis adds one to two dollars to the yearly heating bill (depending on the fuel used). The quantity of outside air brought into a building is controlled by dampers. Dampers are usually poorly maintained; they are located in areas that are very difficult to reach. As a result, inspection and maintenance are often forgotten. This access problem can be addressed by installing access doors in the ductwork or by relocating the dampers.

Damper condition should be checked periodically because damper efficiency and general condition are directly affected by frequency of use. The operation of a damper unit is generally controlled by a damper assembly. A motor mounted at one end of the assembly will control damper positioning.

Damper blades are often made from thin-gauge sheet metal and can warp or twist after extended periods of operation. The damper frame is also fragile, and can be twisted under some circumstances. Frame deformation makes damper modulation difficult. If movement is restricted the damper motor may eventually fail.

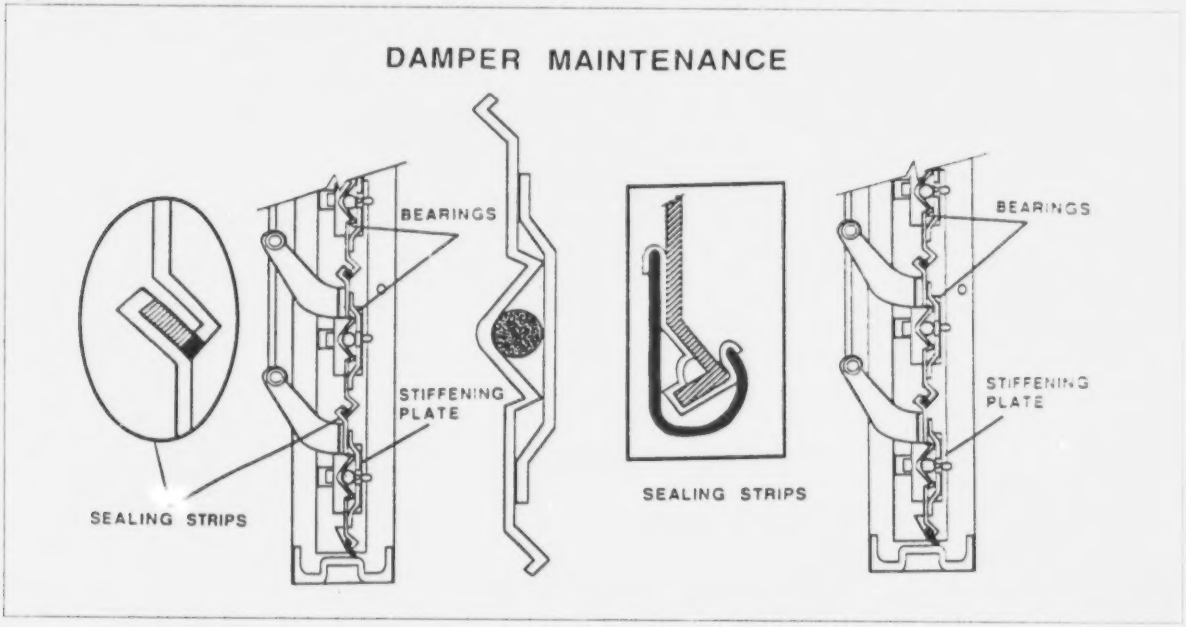
Dampers, even when in good working order, do not close tightly. Air infiltration between the damper blades and around the edge of the unit can be reduced by putting leakage-reducing strips along the edge of each blade and between the ends of the blades and the frame.

Two examples of the application of sealing strips to a set of damper blades are provided in Figure 3.6.

Failed damper motors or seized linkages can cause dampers to remain fixed, instead of modulating towards a minimum position during cold weather or closing when the space is unoccupied. Regular inspection and maintenance, particularly during the winter months, will minimize the energy impact of this kind of damper failure.

Where dampers are used to control the mix of fresh air and return air, it is particularly important to understand the control characteristics of the applicable dampers and ensure proper adjustment of the controls.

Figure 3.6



3.5.2 Air Balancing

Check the ratio of fresh air and return air regularly for proper fresh air supply.

In buildings where air handling system maintenance has been neglected, air distribution to different zones of the building (air balance) is often poor. Poor air distribution can cause discomfort to occupants. Occupant reaction is often to adjust temperature controls or to open windows. Both activities may aggravate ventilation related conditions in other parts of the building and also increase overall energy use.

Poor air balance results in excess outside air being brought into the building, which must then be conditioned (heated, humidified or cooled).

Airflow measurements and air balancing should be carried out periodically, especially if there has been a rearrangement of building zones or a change in internal loads. Air balancing contractors can be hired to do this specialized work. However, it is highly recommended that a building manager ask for, and check references before hiring an air balancing contractor.

3.5.3 Filters

Filter maintenance is another factor which is important in ensuring the energy efficient operation of air handling systems. Filter replacement or cleaning should occur on a regular basis according to the rate of dirt buildup.

Clogging of filters does not increase energy use directly. However, a pressure drop increase of 10% across a filter, due to dirt buildup, will result in an airflow reduction of about 15% and fan power increase of about 10%.

The decrease in airflow can cause a significant imbalance in the ventilation system. Occupant discomfort can prompt window opening and thermostat adjustment.

3.5.4 Humidifier Maintenance

Improperly maintained humidifiers can increase energy use by maintaining a humidity level higher than required.

Humidity controls can also cause excess energy use if they are not regularly calibrated.

If a system is poorly maintained or a regular inspection/maintenance schedule is not followed, humidification may operate throughout the summer, resulting in significant extra energy costs in terms of cooling and dehumidification.

Humidification equipment is also a health concern since some types of humidifiers offer a favourable environment for the growth of micro-organisms. Maintenance procedures should address this concern.

Humidification Coils

Humidification coils should be routinely checked. The best method of inspection is to remove a few eliminator plates and, with a strong light on the opposite side of the coil, check for deposits. Another indication of fouled coils is if there is a significant change over time in the static pressure differential across the coil.

Spray-type humidifier coils must be washed with a detergent and high-pressure water (500 psi). To clean a humidification coil effectively, the coil must be washed from both sides. This means completely removing the eliminator plates.

In addition, a proper water treatment program can eliminate corrosion. Deposit problems associated with spray coil operation can be eliminated through the implementation of a proper water treatment program. One of the essential parts of a water treatment program is the use of a "Quat" type biocide. A good biocide will minimize bacterial buildup and odour. Consult a system service specialist to determine the treatment best for your application.

3.6 Water Treatment of HVAC Systems

An effective water treatment program should maintain a clean system, free of any hard-water scale deposits or any corrosion products. A water distribution system that is fouled with deposits has a much lower rate of heat exchange and will reduce the energy efficiency of the entire distribution system.

An efficient system must be cleaned internally as well as externally. A deposit that has the thickness of a dollar bill at the inside or outside of a heat transfer element, can add as much as 10% to a building's energy cost. To remain clean, a system requires constant inspection and maintenance. The results of a clean system will be lower energy-related operating costs.

3.6.1 Fan Coil Systems

The water flow rate in a fan coil is relatively slow and presents an ideal location for corrosion products to settle. These corrosion products reduce the cooling or heating effectiveness of the coil.

To check for corrosion products in a large fan coil, it is necessary to drain a little water from the bottom of the fan coil header. If there is a black magnetic deposit in the water, this indicates corrosion products in the system and a potential reduction in the heat exchange characteristics of the coil. Another way to check the coil for deposits is to check the coil temperatures with a contact thermometer at the U bends.

Once a newly commissioned system has been cleaned properly to remove all oil and construction debris, a corrosion inhibitor such as boron-nitrite should be added to the system and maintained at all times. A nitrite level between 600 and 800 ppm will protect the system without harming control valves or other control devices. This type of inhibitor prevents dissimilar metal corrosion (copper and steel), which is the major cause of the black magnetic iron oxide deposits found in untreated closed heating and cooling systems.

One of the best methods of removing iron oxide corrosion product from a closed recirculating system is by installing 30-micron size bypass cartridge filters at various points in the system. In addition to serving a cleaning function these filters also provide information on system operation. Any change in the deposit on the filter cartridge may indicate problems in the system. The routine examination of these filters can be incorporated into a preventive maintenance program.

Corrosion coupons are also very useful as a means of monitoring the condition of the system. Corrosion coupons are small preweighed strips of steel or copper placed in the system for specified lengths of time. Coupons should be weighed and checked for signs of corrosion. Their use is highly recommended.

3.6.2 Cooling Tower Condenser Water

The most expensive part of an HVAC system to treat is the condenser cooling tower system. A cooling tower has high water losses due to evaporative cooling and requires water make-up to prevent water deposits from forming on the condenser tubes of the chiller.

Proper water treatment procedures require the use of water scale control chemicals and corrosion inhibitors. This treatment along with the use of low levels of chlorine (0.02 ppm) and filters can maintain condenser

tubes so clean that they may never require brushing. The tubes of a new chiller have a wall thickness of less than 0.75 mm (0.030 in.). Brushing, even when done with care, can damage the condenser tubes.

3.6.3 Domestic Hot Water Systems

For many years the designers of some buildings used galvanized iron piping for the domestic hot water systems. High levels of oxygen in city water, combined with the elevated temperatures of the heating system, can result in severe corrosion of galvanized piping. As this type of corrosion proceeds, the interior pipe diameter is decreased due to buildup. At the same time water temperatures usually have to be increased to compensate for reduced water flow and poorer heat transfer efficiencies.

Domestic hot water temperatures should be closely monitored to reduce excessive scaling. Systems can be flushed and descaled at regularly scheduled intervals to improve heat transfer at the heat exchanger.

3.7 Lighting System Maintenance and Operation

Maintaining adequate illumination levels requires effective lighting system maintenance. An effective lighting maintenance program comprises not only lamp replacement but also routine, planned cleaning of lighting fixtures and room surfaces.

A regular cleaning and relamping program has definite long-term benefits:

- more light is delivered per unit cost of electricity;
- lower -wattage lamps can be installed;
- fewer luminaires can be installed; and
- overall labour costs are reduced.

The optimum period between maintenance servicing is determined by consideration of capital and labour costs, and energy operating costs.

Fluorescent lamps fail at an accelerated rate after reaching 70% of rated life. Light output also decreases as the total burning hours of the lamp increase. For most fluorescent installations the best time to group relamp is between 65% and 75% of average service life. However, the most economical relamping schedule should be determined by consideration of lamp and labour costs for each specific installation.

In many cases, group replacement can be done at a scheduled cleaning time and, in that way, considerable labour savings can be realized. For example, if cleaning is done once a year during vacation shutdown, a group relamping can be done every two or three years depending on the average burning time.

One convenient method of determining the proper time to group relamp is to purchase an additional 10% of lamps and use them for one-at-a-time replacement. When the spare stock begins to get low it is time to group relamp. Besides making labour savings on lamp replacement, group relamping saves on other types of electrical failures in ballasts and starters. Ballasts have been known to overheat and starters can become locked in position when lamps are not promptly replaced near the end of life or shortly after lamps have failed. Replacement of fluorescent lamps with energy-saving lamps can take place either at spot lamp replacement or during group relamping.

Energy saving fluorescent lamps are not recommended for use where ambient space temperature may fall below 16°C. Low ambient temperatures can result in a flickering of the light emitted by the lamps. Also, light output is reduced, the ends of the lamps can discolour, and lamp life is decreased.

In fixtures with two lamps per ballast, low-wattage lamps should not be mixed with standard lamps on the same ballast. The imbalance in voltage and current can result in premature failure.

Caution should be used in installing low-wattage lamps on ballasts which are more than about 15 years old. These ballasts may fail with low-wattage lamps.

Ballast replacement is generally only economical when the existing ballasts need to be replaced. A high rate of ballast failure denotes that existing ballasts are close to the end of their life and require replacement.

Heating Systems 4

4.1 Introduction

Public and commercial buildings incorporate a wide variety of heating systems. This chapter presents examples of a number of typical heating systems and the various measures that can be incorporated into these systems in conjunction with an energy management plan. High-cost improvements involving long-term paybacks are not addressed. Options suggested in this chapter relate to general maintenance and/or low-cost capital improvements.

This chapter need not be read from beginning to end. Rather, select those sections most applicable to the type of heating equipment for which you are responsible. Ideally, do a walk-through of your system with this chapter in hand.

This chapter is divided into six sections:

- Combustion Burners
- Hot Water Plants
- Steam Plants
- Hot Water Distribution Systems
- Steam Distribution Systems
- Forced Air Systems

4.2 Efficiency

The principal goal of an energy management program is to maximize the efficiency of all systems. This section will explain some of the terms used when discussing system efficiencies. Efficiency is a term that describes the relationship between energy input and usable energy output. The heating plant of a building incorporates a number of components that individually are responsible for some form of heat transfer and therefore have their own particular efficiency.

Various terms referring to efficiency will be used throughout this chapter. Outlined below are some definitions.

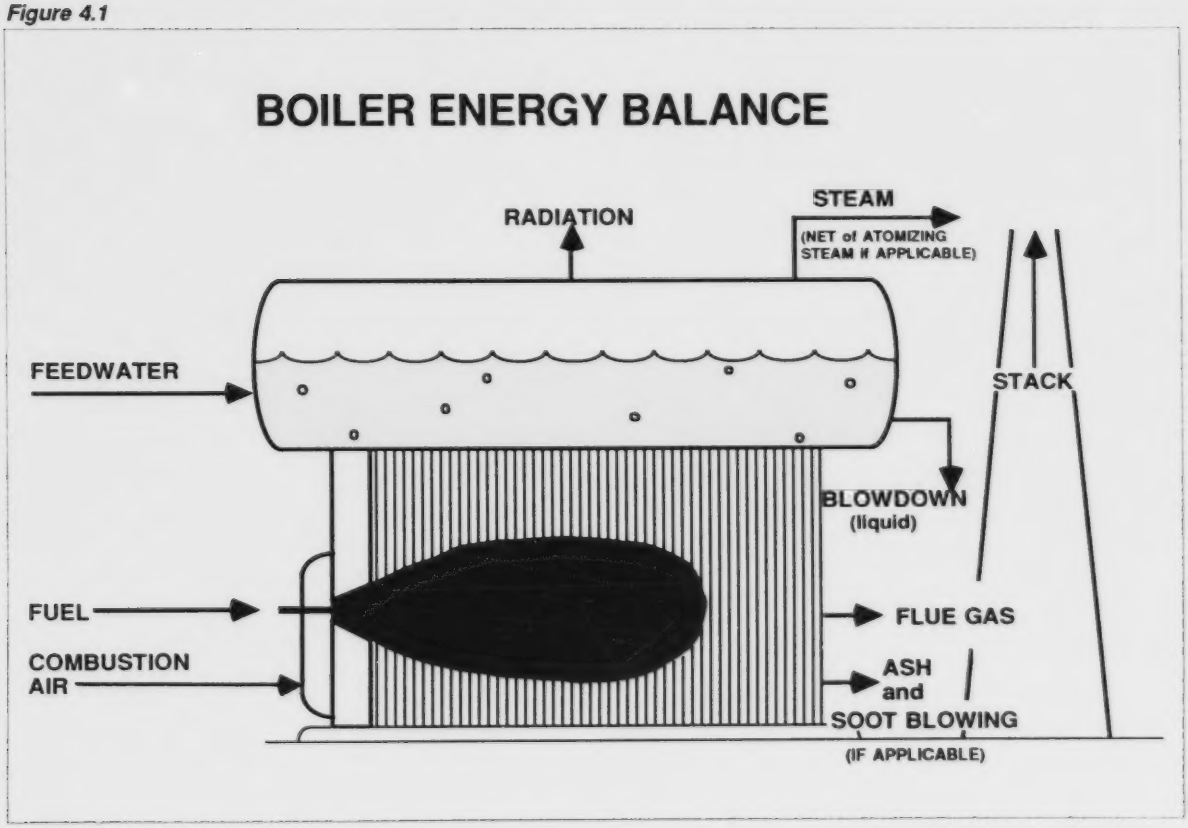
4.2.1 Total Combustion Efficiency

Total combustion efficiency is the relationship between the energy content of the fuel fed into the burner and the energy delivered into the heating distribution system. It is the combination of the burner efficiency and the heat transfer efficiency of the boiler. Total combustion efficiency is an instantaneous value that relates to the performance of the system at any one point in time. Generally, it should only be measured after a period of steady, stabilized operation.

Total combustion efficiency is affected by factors such as:

- cleanliness of the heat transfer surfaces (fireside and waterside);
- burner performance;
- stack temperature;
- combustion air quantity and temperature; and
- burner, boiler and flue construction.

Figure 4.1



Combustion efficiency is determined by measuring the following:

- stack temperature;
- oxygen (O_2) levels in the flue gases (for gas fired burners);
- carbon dioxide (CO_2) levels in the flue gases (for oil fired burners); and
- smoke density.

With incomplete combustion O_2/CO_2 levels in flue gas will be very low. With excess air or combustion, oxygen levels will rise above optimum levels. The graph below demonstrates this relationship for a gas burner.

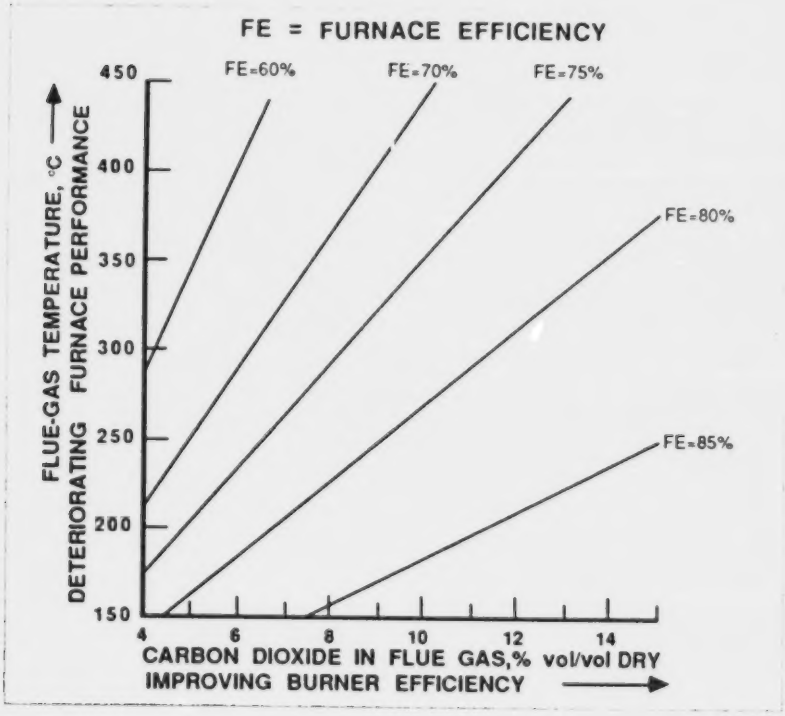


Figure 4.2

4.2.2 Seasonal Efficiency

Seasonal efficiency is the relationship of the fuel consumed over a period of time (e.g. a heating season) compared to the useful heat delivered to the heating distribution system. When a heating cycle begins, the boiler and flue may be cold; therefore it may have to be heated before useful heat can be transferred to the system. When the burner stops operating, drafts through the firebox and the flue will again cool down the boiler and the flue, contributing further to a reduction in the normal operating efficiency. Seasonal efficiency is a value which averages those periods of lower and higher efficiency. For example, a system that has a total combustion efficiency of 80% may only have a seasonal efficiency of 65%.

Some factors which affect seasonal efficiency are:

- system operation,
- matching system size with heating demand, and
- burner/boiler construction.

4.3 Combustion Burners

Combustion burners are designed to control the combustion of fuel with air. Regardless of the energy source or of the type of burner, the common components are:

- a diffuser to mix the fuel with air,
- an air supply (natural or forced),
- an ignition device, and
- a photocell to recognize the presence of fire.

The actual burner configuration will vary depending on the type of fuel used. Oil, for example, has to be atomized before being mixed with air and ignited. This atomizing is done by pressurizing the oil and forcing its flow through the orifice of a nozzle. If heavier oils are being used (No.5 heavy or No.6), the atomizing process is better achieved by mixing steam or compressed air with the fuel before it reaches the atomizing nozzle. Natural gas does not require atomizing since it is already a gas.

Air can be drawn to the burner by the natural draft occurring above the burner. However, on larger burners, natural draft is usually insufficient and must be supplemented with a blower that controls the air quantity more precisely.

Ignition of the fuel can be achieved by a pilot mechanism or electronic spark ignition.

The photocell element of the burner is a safety device intended to sense combustion. If combustion has not occurred soon after startup the system is immediately shut down.

Burners using conventional fuels can be divided into four groups;

1. high-pressure atomizing oil burners,
2. steam or air atomizing oil burners,
3. atmospheric gas burners, and
4. power draft gas burners.

Energy management measures for each of these burner types is discussed in greater detail in each of the following sections.

> Caution:
> Burner maintenance should be carried out by qualified professionals. In some cases a licence may be required to service certain types of burners.

4.3.1 High-Pressure Atomizing Oil Burner

A high-pressure atomizing oil burner is commonly found in older heating plants serving large buildings or a series of buildings. A number of methods can be used to upgrade the performance of this type of burner.

1. Sizing The Burner

When selecting a new burner to be incorporated into a new or existing system, it is highly recommended that you try to size the burner for maximum efficiency. This can be achieved by selecting a nozzle that will provide adequate heating when operated for 20 to 22 hours on the coldest winter day (design low temperature).

2. Adding A Flame Retention Head

Efficiency of older oil burners can be improved by adding a flame retention head. The flame retention head fits on the end of the oil burner and improves the dispersion of the flame, allowing for more complete combustion of the fuel. Proper sizing of the retention head is very important and it is recommended you consult with a oil service specialist. Most new oil burners are equipped with a retention head as standard equipment.

3. Delayed-Action Solenoid Valve

Burner efficiency is often reduced during the initial stages of firing up and also during burner shutdown. For up to the first 30 seconds of startup, combustion can be incomplete. Incomplete combustion can be one of the major causes of soot buildup in an oil combustion system. This is often caused by low pressure in the fuel line, as the fuel pump starts up. Incomplete combustion can also occur at the end of the firing cycle if the fuel pump fails to immediately shut itself off, causing burner run-on.

Both problems can be solved by installing a delayed-action solenoid valve between the fuel pump and the nozzle. The solenoid valve allows pressure to build up in the oil line before combustion takes place. This delay also gives the induced draft fan time to build combustion airflow to the required level. The solenoid valve is also designed to turn off the fuel flow sharply, thereby eliminating burner run-on. This type of modification will also reduce the frequency of cleaning required due to soot buildup.

4. Multi-Stage Burners

If a furnace incorporates a multi-stage burner, it should be adjusted to ensure maximum use of the low-fire operation. Low fire operation is generally associated with longer operating periods and greater seasonal efficiency.

5. Modulating Burners

In combustion systems incorporating modulating burners, a drop in efficiency can suddenly occur if the air/fuel controller slips out of adjustment . Loose connection rods are a common cause.

6. Burner Maintenance

The actual heat content of fuel oil may vary slightly over time. To ensure maximum efficiency, combustion airflow should be adjusted on a monthly basis and whenever there is a deliberate change in the grade of fuel oil being used.

Airflow is very important in modulating burners and the fuel/air ratio should be checked and adjusted on a regular basis. Loose connecting rods will often affect fuel/air ratio settings.

Burner efficiency as well as carbon dioxide (CO_2) and oxygen (O_2) levels should also be checked on a regular basis. Consider installing a permanent efficiency meter or oxygen analyzer in the flue to allow continuous monitoring of combustion efficiency.

4.3.2 Steam or Air Atomizing Oil Burners

Steam or air atomizing oil burners are usually found on larger capacity systems. Some methods of upgrading these types of burners are discussed below.

1. Conversion from Steam to Compressed Air
Depending on the grade of oil being used it is sometimes possible to reduce the cost of atomizing by converting from steam to compressed air. However this is only applicable for the higher grade, lighter oils.

2. Reduce Burner Cycling
To increase seasonal combustion efficiency, burner cycling can be reduced by increasing the steam pressure range on the main pressure controller.

3. Pick the Lowest Cost Fuel
Relative prices of light oil, heavy oil, and natural gas fluctuate. Use the fuel with the lowest cost per unit of energy. Keep in mind long-term trends and be sure to consider the capital cost to convert.

4. Install an Oxygen Trim Control
If the steam-generating capacity of a heating system is over 3000 kW (10 million BTU/Hr), it may be worthwhile to install an O_2 trim control . This type of control automatically adjusts the amount of air fed to the burner based on the percentage of O_2 detected in the flue gas.

5. Differential Pressure Regulation
Adjust steam pressure in relation to the oil pressure to achieve best efficiency.

On large systems consider installing a differential pressure regulator to control the steam pressure. Efficiency is improved by achieving a more consistent operation of the atomizer.

Consider use of recovered waste heat to preheat the heating oil where the system uses heavy oils.

6. Maintenance
In systems using heavy oils, oil viscosity can have a significant effect on burner efficiency. Viscosity is directly related to the temperature of the oil. If possible, the oil in its holding tank should be maintained at a constant temperature.

4.3.3 Atmospheric Gas Burners

Atmospheric gas burners rely on naturally induced drafts for combustion. Household gas furnaces and older large-scale systems often utilize atmospheric gas burners. In many cases this type of burner may have replaced an original oil fired burner. This section outlines methods of upgrading the performance of this type of burner.

1. Electronic Ignition
Over the course of a year a continuously burning pilot light can consume a considerable amount of gas. An electronic ignition system can eliminate the need for a constantly burning pilot flame.

2. Reduce Burner Cycling
Frequent on/off operation can reduce the efficiency of a burner when considered over a long-term period. This type of cycling can be reduced by increasing the pressure range between cut-in and cut-out on the control regulating burner operation.

3. Monitor Manifold Gas Pressure
The operating efficiency of an atmospheric gas burner is dependent on the manifold pressure of the gas feeding the burner and the proper mixing proportions of air and gas at the flame. Periodically check the manifold gas pressure to ensure it is set to the proper specification for the burner being used. The air/gas mixture of the burner can be optimized by first adjusting for flame colour. Efficiency can be further optimized by taking efficiency tests concurrently with adjustment of the air-blending regulator.

4. Maintenance
Because this type of system relies on natural drafts created by the combustion process, air inlets into the boiler room should be open at all times. Regularly check dampers and filters to ensure that free flow of air is maintained. It is also important to keep the boiler room uncluttered and dust-free to minimize fouling of the burner.

Unnecessary use of gas can be reduced by turning off the pilot flame when the burners are out of service. For example, if the burner is only being used for space heating the pilot can be turned off during the summer months.

4.3.4 Power Draft Gas Burners

Power draft gas burners rely on a fan to provide sufficient air for combustion and venting of flue gas. This section outlines methods of upgrading the performance of this type of burner.

1. Upgrading Burner Efficiency
Methods to increase burner efficiency for power draft burners are similar to those for other types of burners. For example, older burners can be fitted with a retention head. On/off cycling can be reduced by increasing the on-off range on the burner control.

Efficiency on larger systems of 3,000 kW (10 million BTU/Hr), or more capacity can be improved by installing an airflow trim control operated by a flue gas sensor.

4.4 Hot Water Plants

A hot water plant may include one or several hot water boilers, a heat exchanger to produce domestic hot water, circulating pumps, and control devices. Figure 4.3 presents a schematic of a typical plant layout.

The common energy sources for hot water boilers are oil and gas. Electricity, wood, or other energy sources may also be used.

Note: Measures applicable to the water distribution system appear in Section 4.6 and those applicable to the domestic hot water system in Chapter 5. Burners are also covered separately in Section 4.3.

The notes below describe energy management opportunities relating to the numbered components of the hot water system in Figure 4.3. The first section presents measures that might be made to upgrade the system. The second section discusses key energy related maintenance measures that should be undertaken on a regular basis.

4.4.1 Upgrading the Hot Water System for Energy Performance

1. Indoor/Outdoor Temperature Controller
The heating demand of the building will vary with the outside air temperature. An indoor/outdoor controller can be used to adjust the hot water supply temperatures in response to changing outdoor temperatures. The temperature of the water should be monitored where it enters the hot water distribution system (inlet).

In a small system where an automatic control system is not cost-effective, the hot water supply temperature should be adjusted manually (weekly or monthly).

2. Burner
Refer to section 4.3 for upgrading and maintenance suggestions for the type of burner applicable to your system.

3. Measuring for Energy Performance at the Stack
Control combustion efficiency by constantly monitoring carbon dioxide (CO_2) and oxygen (O_2) concentrations. Consider installing permanent efficiency and/or O_2 sensors in the flue gas breeching just above the boiler.

4. Install Run Time Meters in Control Panel
Add running time meters on non-modulating burners to be monitored daily as part of an energy monitoring program. Run time meters can be used to monitor use of each boiler and sequence boilers correctly according to heating demand.

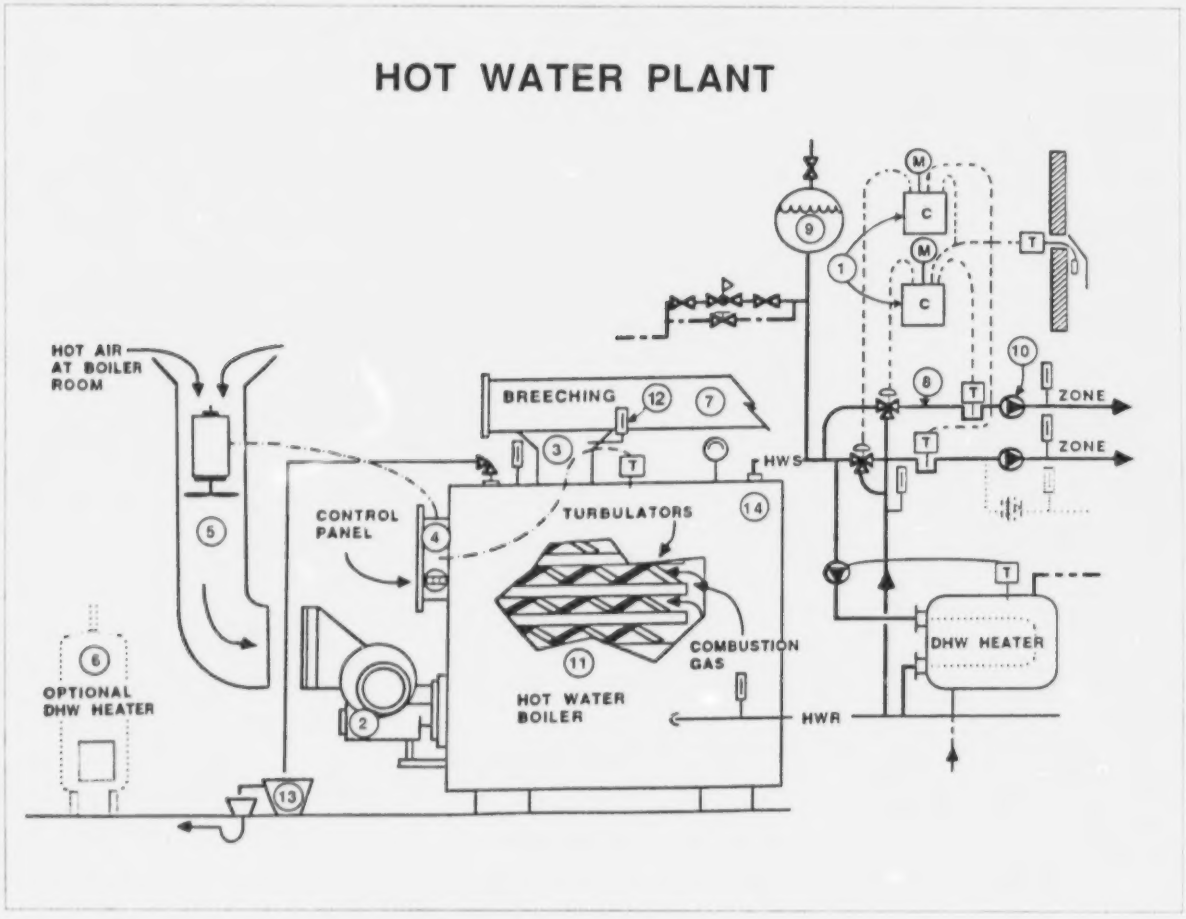
5. Destratification
In a hot boiler room, use a fan and ductwork to bring hot air down to the burner air inlet. This procedure will improve combustion efficiency.

6. Domestic Hot Water Heater for Summer Use
Consider shutting off main boilers and using self-contained heating units for domestic hot water in summer months.

7. Heat Recovery from Flue Gas (Flue Gas Economizer)
Install a flue gas economizer to preheat domestic hot water or to reclaim heat for other uses. Be sure to obtain professional advice before installing any type of heat recovery unit.

8. Boiler and Circulation System
Decrease radiant heat losses by ensuring proper insulation on boilers, pipes, valves, etc. If necessary, replace poor insulation.

Figure 4.3



4.4.2 Maintenance for Optimum Energy Performance

9. Expansion Tank
Maintain adequate air in expansion tanks. Check operation of expansion tank. Insufficient expansion capacity results in unnecessary loss of hot water through the relief valve when the boiler cycles on and off.

10. Circulating Pump
Bleed off air weekly during the heating season.

Check relationship of pump to expansion tank to ensure proper operation. Air binding of the pump will cause cavitation and damage to the pump. Air in heating systems will cause localized heating problems and result in the necessity of higher hot water temperatures for heating. If piping changes are considered necessary, get professional advice.

11. Combustion Chamber/Flue
Unnecessary energy losses can occur as a result of excessive heat escaping the boiler unit via flue gases. As a rule of thumb, the

temperature of flue gas should be no more than 100°C (180°F) above the boiler water temperature at the inlet to the distribution system. High flue gas temperatures indicate excess air in the fuel /air mixture or a fouled heat exchanger surface. They may also indicate insufficient water flow.

Consider installing turbulators where possible to increase the heat transfer from the firetubes.

12. Heat Exchanger Fouling

A slow increase in flue temperatures over time may indicate fouling of the boiler tubes. Monitor and record flue gas temperatures and check for variations as a part of regular maintenance. If variations are detected inspect the boiler (fire side and water side).

13. Relief Valve

The relief valve on the top of the boiler is designed to purge water from boiler system if the water pressure exceeds a set limit. Monitor the relief valve by installing a container between the relief outlet and floor drain to check for presence of water. Make sure the valve is properly adjusted. If water is present, check the high limit settings on the burner control. Also check the expansion tank.

14. Keep Circulation System Clean

Monitor water treatment and avoid scale buildup on water tubes. Inspect fire side for corrosion caused if the flue gas temperature drops below the dewpoint of the acids contained in the flue gases and if excessive humidity (condensation) builds up when the boiler cools down.

For Hot Water Systems Incorporating Standby Boilers:

Energy losses from stand-by boilers can be reduced by incorporating controls to operate the boilers in series sequence. In addition, the supply temperature should be reset periodically in accordance with the outside temperature. This can be achieved using manual or automatic control.

Use check valves or manual/automatic valves to prevent short circuiting of water flow through stand-by boilers and pumps.

In large boilers, consider automatic dampers between the boiler and the flue to prevent heat losses during the off cycle.

4.5 Steam Plants

Steam plants are generally more complex than hot water plants and also include more equipment. A schematic of a typical steam plant is presented in Figure 4.4. Major components of the system are described below, along with recommendations for energy related measures for upgrading and maintenance:

- deaerator to remove air from condensate and make-up water.
- condensate tank to recover and accumulate condensate water.
- water softener to remove hardness in make-up water.
- chemical tank for the supply of chemicals to the boiler as a means of controlling pH and other important water conditions.
- blow-down receiver to allow the removal of foam and other undesirable floating material in the boiler at the water surface.
- blow-down line to remove sludge that accumulates at the bottom of the boiler as a result of water treatment and concentration of solids.

The notes below describe a variety of energy management measures that can be applied to the areas identified in Figure 4.4.

4.5.1 Upgrading the Steam Plant for Energy Performance

1. Combustion Air
The hottest combustion air available should be provided to the burner. Stratified hot air at the ceiling level can be ducted to bring stratified hot air down from the ceiling to the burner air inlet. This will improve combustion efficiency.

2. Flue/Stack
Consider installing heat recovery devices if the boiler operates more than 6,000 hours per year. Obtain professional advice before installing any type of heat recovery device. Boiler construction and stack temperature permitting, turbulators can be installed in the firetubes as an alternative to, or possibly supplement, heat recovery equipment.

3. Oil Heater
The oil heater is required to maintain heavy bunker oil (No. 6 oil) at approximately 50°C (122°F) to ensure good flow and combustion. If oil is heated it is recommended that oil storage tanks be thermally upgraded and heated using recovered waste heat.

4. Heating Lines
To reduce line heat losses insulate all heated lines and surfaces including steam, oil, condensate return, deaerators, etc. This also includes large valve bodies.

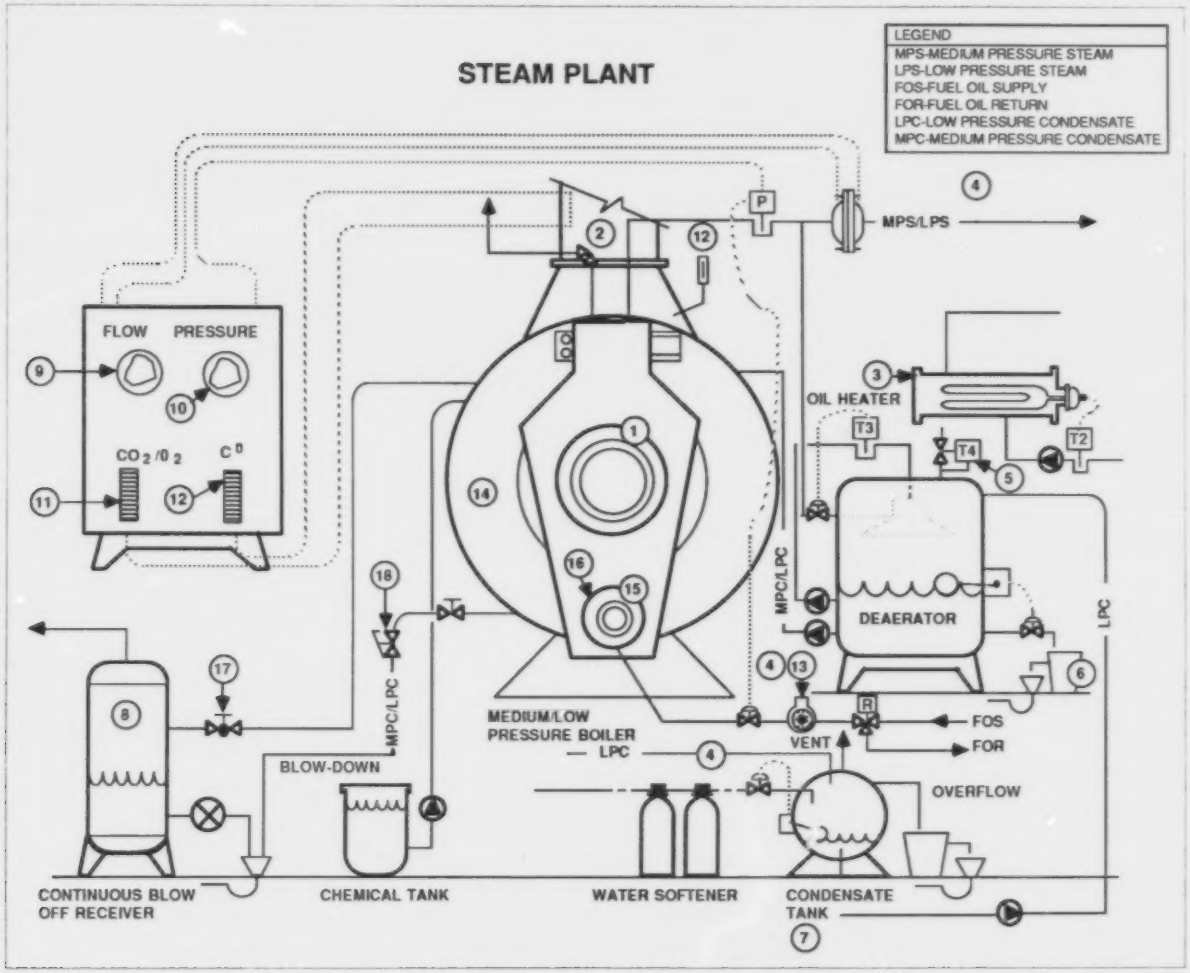
5. Deaerator Thermostatic Vent
The deaereator is designed to remove air from the condensate and make-up water before it is introduced back into the system. Install a thermostatic vent on deaerator to reduce steam losses.

6. Holding Tank
Losses from safety valves or overflow drain lines can be avoided by installing a liquid holding tank on line outlet above floor drain.

7. Condensate Tank
The condensate tank is intended to recover and accumulate condensate water from the system. Be sure that the condensate tank is sized to adequately accommodate all condensate overflow from the system.

8. Heat Recovery from the Blow Down
If boiler has continuous blow down, consider installing a heat exchanger or vent.

Figure 4.4



4.5.2 Maintenance for Optimum Energy Performance

9. Chart Recorder for Steam Production
Steam production should be monitored and evaluated in conjunction with fuel consumption of the boiler at least on a daily basis as a check of the system efficiency. The chart recorder is usually calibrated to a fixed steam pressure. If this pressure varies the recorder loses its accuracy. If there is a constant variation in the actual steam pressure from the calibrated value a conversion factor must be applied to the recorded steam quantities to determine the true steam flow values.

Using the information from the chart recorder the overall efficiency of the steam plant including water make-up loss should be calculated regularly using the following formula:

$$\text{Overall Efficiency (\%)} = \frac{S \times H \times 100}{V \times Q}$$

where: S= Steam produced (kg) - from Chart Recorder
H= Heat content of steam (MJ/kg) - see Steam Tables
V= Volume of fuel (liters) - from Fuel Meter
Q= Heating value (MJ/unit volume) - from Fuel Tables

10. Steam Pressure Recorder

Steam pressure generally varies from 100 kPa to 1,000 kPa (14.5 to 145 pounds per square inch). To minimize piping losses, calculate the lowest steam pressure needed for each time of year (based on heating demand) and regulate the pressure on a seasonal basis. Also, consider night setback of steam pressure if a lower pressure can be used at night.

Caution: Certain high-pressure boilers must maintain a specified minimum pressure to operate properly for example, sterilizers may require 500 KPa (70 psi).

11. Flue Gas Carbon Dioxide (CO_2) And Oxygen (O_2) Monitors

Carbon dioxide and oxygen levels in the flue are related directly to the burner combustion efficiency. Monitor CO_2 and O_2 flue gas indicators regularly and adjust controls for maximum efficiency. For more information on the control of burners refer to section 4.3.

12. Flue Gas Temperature Indicator

Record flue gas temperature each shift and check for a gradual increase. This will indicate gradual fouling of the heat transfer surfaces.

13. Fuel Measurement

A daily log of fuel consumption should be kept. Fuel consumption can be measured with a fuel meter or determined by other methods such as:

- Recording oil levels in the storage tanks with a dipstick or a level indicator.
- Recording delivery of fuel oil.
- Recording the burner operating times with a run time meter.

14. Steam Boiler

To avoid stand-by boiler losses the boiler should be operated at the best efficiency for the heating load required. If a stand-by boiler needs to be on line, keep it hot with steam injection rather than by running a burner.

15. The Burner

Section 4.3 deals with the burners in detail.

16. Lever Settings on Burner Assembly

Confirm lever settings on burner assembly. Check regularly both on and off positions to determine flow.

17. Blow-off Valve (Continuous Blow-down Valve)

Adjust to avoid excessive blow off and blow down but ensure adjustment is sufficient to allow purging of impurities and sludge from the system.

18. Blow-down Sampling Valve

The efficiency of the blow-down should be checked monthly using chemical tests.

4.6 Hot Water Distribution Systems

A hot water distribution system, sometimes called a hydronic system, is used to circulate hot water between a boiler and the heat transfer equipment located in the various heated areas of the building. Figure 4.5 provides a schematic of a typical system.

The main components of the system are listed below.

- Piping/heat distribution system.
- Heat transfer equipment including:
  - convectors generally installed in occupied areas,
  - forced flow heaters for vestibules,
  - unit heaters for shops, garages and equipment rooms, and
  - heating coils installed in air handling units or in heat exchangers such as a DHW heater
- Pumps to circulate the heating water.
- Control devices that regulate the water temperature and the water flow in the heat transfer equipment and prevent air accumulation in the piping (identified by C1 through C3 in Figure 4.5).
- Monitoring devices to read pressure and temperature at various locations in the system (identified by T1 through T10).
- All setback operations are controlled by a central timer (located in the bottom left hand corner of Figure 4.5). The timer has three circuit connections.
  - connection R1 is programmed to indicate the setback period for the water circulation temperature of the system.
  - connection R2 controls the cycling times of fans on unit heaters when in the setback mode.
  - connection R3 is programmed to signal unoccupied periods of the building for the sequencing of setback thermostats.

The notes below describe the components identified in Figure 4.5 that offer key energy management opportunities.

4.6.1 Upgrading the Hot Water Distribution System for Energy Performance

1. Temperature Control and Air Distribution
To reduce heat loss during unoccupied periods install setback thermostats in areas where feasible. Set unoccupied periods to timer connection R3 . In addition, distribution fans can be cycled to maintain the setback temperature throughout the room(s), via timer connection R2.

Note: In some cases, the heating coil may freeze up unless freeze protection is included. If necessary check with an expert.

4.6.2 Maintenance for Optimum Energy Performance

2. Unit Heaters
During unoccupied periods the heater fans can be set to start and stop via a setback thermostat control. The setback timer would be connected to contact R2 on the main timer.

3a. Convectors
Setback temperatures can be achieved at room convectors by decreasing water temperature during unoccupied periods. A second water temperature control (C1A) is programmed for the desired setback temperature. Timer will switch from control C1 to C1A through an electro-pneumatic (EP) valve and contact R1 on the main timer.

3b. Convectors (An Alternative Setback Approach)
An alternative setback method can be achieved using dual-pressure pneumatic control and corresponding dual setpoints. The air pressure is set by a dual-pressure system involving an EP valve controlled by a timer and contact R1 on the main timer.

4. Forced-flow Vestibule Heaters
Set temperature of forced-flow heaters in vestibule to maintain 5-7°C (42-45°F) (check operation of door closing mechanisms).

5. Pump Pressure Drop Measurement Device
To reduce over-pumping, monitor pressure drops in piping with the typical arrangement shown at 2b in the bottom right hand corner of Figure 4.5.

6. Automatic Air Vents
Check all automatic air vents for buildup of air in the system and for leakage. Install air vents where required to prevent air locks in the circulation system.

7. Location of Circulation Pumps
The relationship of the circulation pumps to expansion tank may contribute to the introduction of air into the system. Air binding is prevented when expansion tank is connected at suction side of pumps; however professional advice should be sought prior to any changes.

8. On/Off Pump Operation
System seasonal efficiency can be improved by turning off all circulating pumps during temperature setback (connection R3) or unoccupied periods when outside temperature is above 15°C (59°F). Care must be taken to prevent freeze-up of pipes in remote/exposed areas.

9. Seasonal Inspection and Maintenance
Radiant heat losses from the distribution system and the boiler itself can be reduced by insulating bare pipes and valves, and repairing damaged insulation.

In addition, the boiler should be operated at the lowest water temperature compatible with the comfort requirements of the building. This can be done many times over the year to correspond with the actual heating demand.

10. Domestic Hot Water Supply
Reduce consumption by use of flow control devices and user instructions.

11. Heating/Cooling Loops
Close off heating (or cooling) loops as soon as heating (or cooling) period is over. **Note:** With electric heating, open breaker switch controlling heating elements.

12. Temperature Controls
The setpoint on the temperature controls can be adjusted to ensure the supply system is delivering the lowest possible temperature compatible with building comfort (**Note:** temperature should be measured after mixing valve).

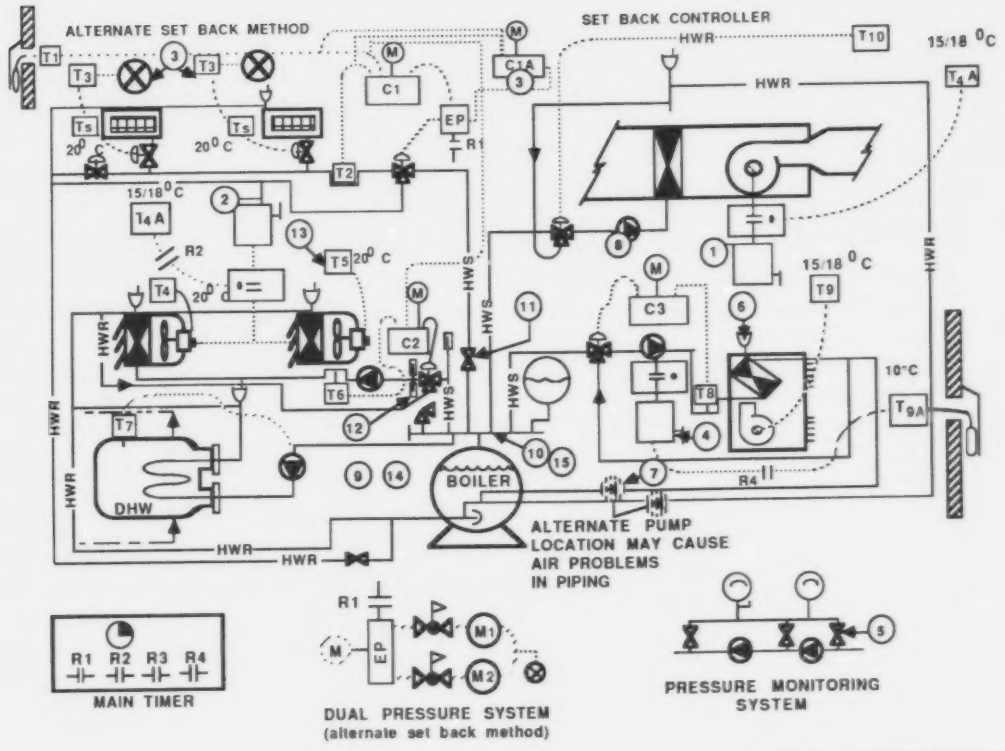
14. Thermostats
On an annual basis check the setpoint of all thermostats against actual room temperature. If the temperature deviation exceeds 1°C (1.8°F), recalibrate the thermostat.

Where feasible, consider the use of self-contained thermostatic valves. Use individual thermostats rather than zone control where possible.

15. The Water System
Monitor water for dirt, scale and corrosion regularly. Flush system as required to maintain clean surfaces for good circulation and heat transfer. Use water treatment where applicable.

Figure 4.5

HOT WATER DISTRIBUTION SYSTEM



4.7 Steam Distribution Systems

A steam distribution system is used to convey steam from a boiler to the heat transfer equipment. Figure 4.6 provides a schematic of a typical steam distribution system.

The main components of a steam distribution system are described below:

- piping (usually steel).
- heat transfer equipment:
  - convectors generally installed in occupied areas
  - forced-flow heaters for vestibules
  - unit heaters for shops, garages and equipment rooms
  - heating coils installed in air-handling units or in heat exchangers such as a domestic hot water (DHW) heater
  - humidifiers in ventilating units.
- condensate handling equipment with condensate tank, pump and water make-up supply line.
- control devices that regulate the steam flow to the heat transfer equipment and maintain the steam within the equipment.
- monitoring devices to read pressure and temperature at various locations in the system (identified by T1 through T10).
- all setback operations are controlled by a central timer (located in the bottom left hand corner of Figure 4.6). The timer has three circut connections.
  - Connection R1 is programmed to indicate the setback period for the domestic hot water circulation system.
  - Connection R2 controls the cycling times of fans on unit heaters when in the setback mode.
  - Connection R3 is programmed to signal unoccupied periods of the buidling for the sequencing of setback thermostats.

The notes below describe the components identified in Figure 4.6 as offering key energy management opportunities.

4.7.1 Upgrading Steam Distribution for Energy Management

1. Temperature Control and Air Distribution

To reduce heat loss during unoccupied periods install setback thermostats in areas where feasible. Set unoccupied periods to timer connection R3 . In addition, distribution fans can be cycled to maintain the setback temperature throughout the room(s), via timer connection R2.

Note: In some cases, the heating coil may freeze up unless freezing protection is included. If necessary check with an expert.

4.7.2 Maintenance for Optimum Energy Performance

2. Unit Heaters

During unoccupied periods the heater fans can be set to start and stop via a setback thermostat control. The setback timer would be connected to contact R2 on the main timer.

3. Convectors

Setback temperatures can be achieved using dual-pressure pneumatic control and corresponding dual setpoints. The air pressure is set by a dual-pressure system involving an EP (electro-pneumatic) valve controlled by a timer and contact R1 on the main timer.

4. Forced-flow Vestibule Heaters
Set temperature of forced-flow heaters in vestibule to maintain 5-7°C (42-45°F) (check operation of door closing mechanisms).

5. General Maintenance
Seasonal efficiency can be improved by turning off the steam supply during unoccupied periods when outside temperature is above 15°C (59°F). Add valve with controller and an outside temperature sensor.

Reduce steam pressure in the system whenever possible and maintain insulation on distribution system.

6. System Shutdown
Turn off steam supply as soon as the heating season is over.

7. Humidifiers
Turn off the steam to humidifiers as soon as humidification pericd is over.

8. Condensate Tank Vent
To stop steam and/or condensate losses check the condensate tank vent regularly for steam trap leakage.

9. Steam Traps
Inspect all steam traps once a year.

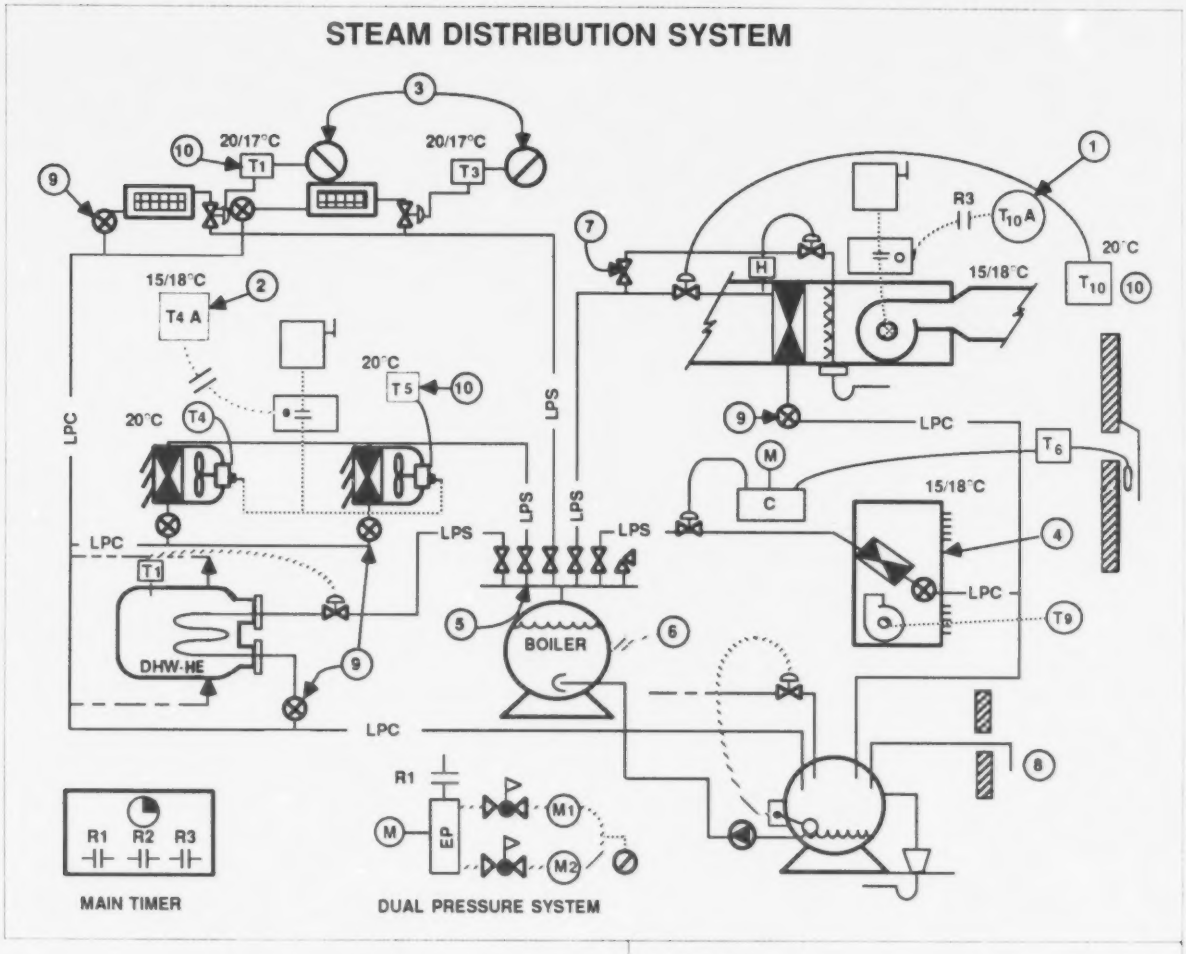
10. Thermostats
On an annual basis check the setpoint of all thermoststs against actual room temperature. If the temperature deviation exceeds 1°C (1.8°F) recalibrate the thermostat.

Where feasible, consider the use of self-contained thermostatic valves.

Use individual thermostats rather than zone control where possible.

An alternative strategy to control steam heating systems according to outside temperatures is the use of a "pulse control".

Figure 4.6



LEGEND

LPC – Low Pressure Condensate
LPS – Low Pressure Steam
DHW-HE – Domestic Hot Water Heat Exchanger
EP – Electro-Pneumatic Device
M – Controller Actuator

4.8 Forced-air Systems

A forced-air heating system uses air circulated through the building with a fan to convey heat from the source, i.e. the furnace, to the required location. It is commonly used in residential buildings.

The main components of the system are listed below:
- furnace/heat exchanger (usually incorporating the fan and the filter);
- fan to circulate the air;
- filter to remove particulate contaminants;
- duct/heat distribution system;
- control and safety devices to regulate the air and the space temperatures; and
- optional night setback timer.

The notes below describe the key energy management opportunities for forced air systems.

1. Furnace
- Refer to Section 4.3 for burner operation and maintenance.
- Keep heat transfer surfaces clean.

2. Fan
- Increase the fan speed where the flue gas temperature is above normal levels.
- Increase the "on" time by lowering the thermostat settings to a high of 60°C (140°F) and a low of 40°C (100°F). Do not alter the high temperature safety control!
- In some cases continuous operation of the circulation fan will avoid air stratification in the building and provide better heat distribution throughout the building.

3. Filter
- Clean or change regularly.

4. Duct System
- Clean regularly.
- Insulate ductwork in cold areas.

5.1 Introduction

Domestic hot water systems provide potable water for handwashing, showers, baths, dishwashing and cleaning. Most commercial buildings incorporate some form of domestic hot water heating system.

The domestic hot water system is similar to hot water heating systems except that the heated water is potable and cannot be chemically treated. Cold water is supplied as make-up to this system from the local water utility.

Domestic hot water systems can be subdivided into unitary and central systems. Unitary systems are point-of-use systems with no distribution piping to serve multiple points of use. Unitary systems, or instantaneous water heaters, eliminate long pipe runs and associated line losses.

Central systems are more common and will incorporate distribution piping to serve more than one point of use. A central domestic hot water system generally includes the components listed below:

- a hot water generator heated by steam, by natural gas, or by an electric element;
- a storage tank (frequently integrated with the hot water generator);
- piping (usually copper pipes);
- recirculating pump(s);
- plumbing fixtures such as faucets, showerheads, etc.; and
- control devices that regulate the water temperature and occasionally the water flow to the appliances.

Figure 5.1 provides a schematic of a typical domestic hot water system. This chapter provides a checklist of energy management measures applicable to a domestic hot water system.

5.2 Domestic Hot Water Energy Management

The notes below describe the key energy management measures related to various components of the system identified in Figure 5.1.

1. Install Check Valves

a) A check valve is designed to make sure water will flow in one direction through a particular segment of a pipe.

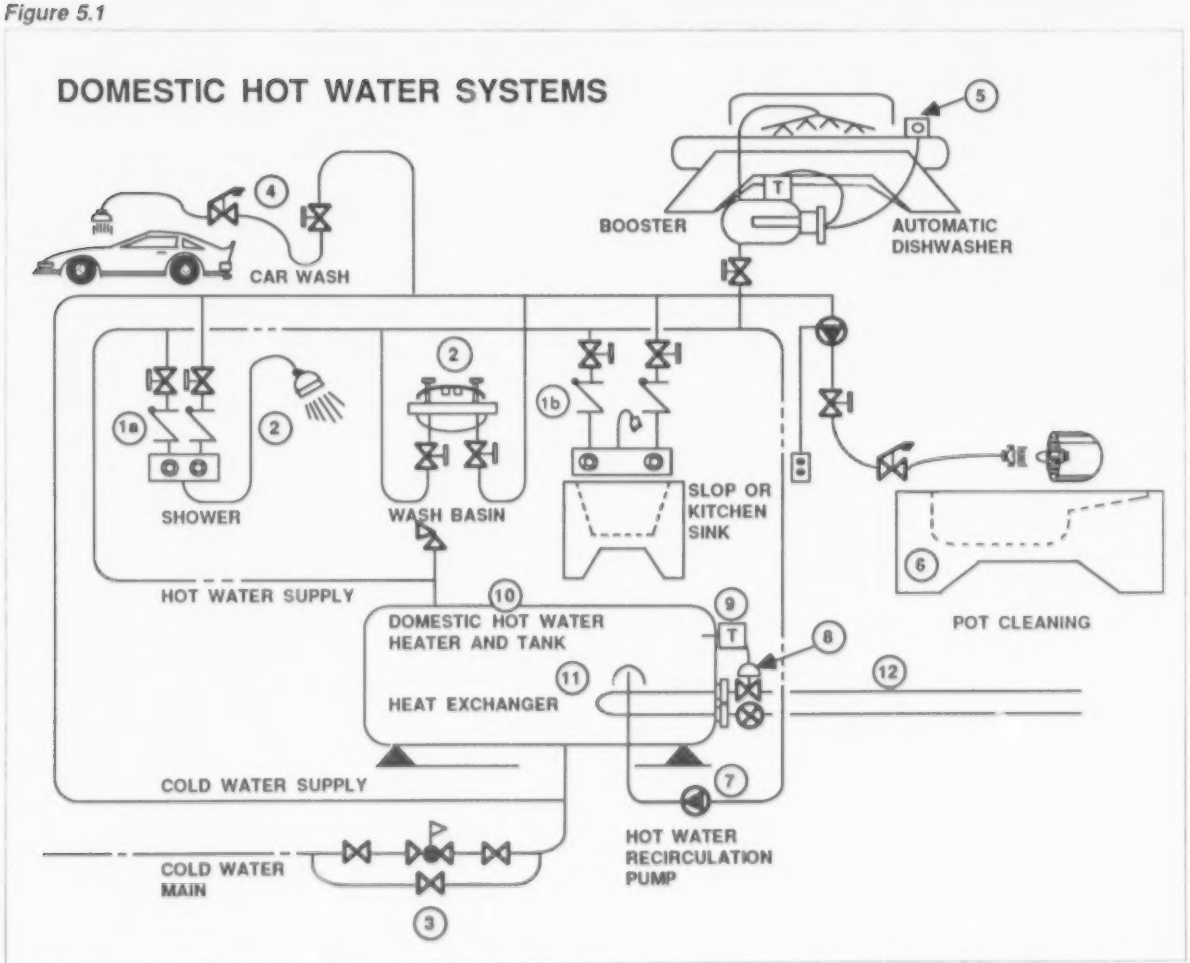
b) Check valves should be added to all fixtures incorporating a mixing tank or utilizing a single faucet. In case of differential pressures between the hot and cold water lines check valves will prevent backflow of one delivery system into another.

2. Showerheads and Faucets

Hot water consumption can be reduced through the use of restricted water flow showerheads, 0.25 L/s (3 GPM imp.). In areas of high use also consider pushbutton valves to operate faucets.

Adjust gate or globe valve under fixtures to limit water flow to 0.075 L/s (1 GPM) in washbasin and 0.15 L/s (2 GPM) in sinks. (These recommendations are not applicable where stop cock and stop valves are used.)

Figure 5.1



3. Main Water Entry
Lower supply water pressure (and flow). The supply pressure at main water entry can be reduced to obtain 110 kPa (16 PSI) at top end of distribution line at peak consumption period. Lowering the pressure will in turn reduce flow rates at point of use. Although this procedure will not reduce water use for a bath where a fixed quantity of water is required, it will reduce water use for handwashing and showers which are time-dependent uses of hot water.

Note: This may not work in all buildings. Check operation of mixing valves where hot and cold water mix. If the pressure difference between hot and cold water lines is too great, this measure should not be used.

4. Washing Floors and Vehicles
To wash vehicles and floors, use cold water only.

5. Dishwashers
On dishwashers, add a photocell, with time delay relay, to turn off the hot water booster after dish trays have been removed.

6. Dishwashing Sink
Replace hot water pot cleaning with a strong cold water spray operated by a pressure pump if possible.

7. Piping Distribution System
To reduce piping losses stop recirculating pump one hour after occupied period ends. Restart the recirculation pumps not more than one hour before the occupancy period begins. Reduce size of the circulating pump to pump not more than 1 L/s to save electrical energy for pump motor and minimize line losses.

8. Hot Water Tanks
To reduce tank losses turn off the water heater when hot water will not be used for a period of 72 hours or more.

9. Hot Water Tank Thermostat
It also is recommended that water temperature be reduced to 60°C (140°F) in buildings with showerheads and to 45°C (113°F) in other buildings. Check water temperature at point of use as well as tank temperature. (This is also an important safety measure to prevent scalding, especially of young children and the elderly.)

10. Hot Water Tank Insulation
Tank and lines should also be insulated to avoid unnecessary losses. Check economics of tank and line insulation for each system and provide insulation where economical. Seal off vertical risers to reduce air movement and thermal losses from pipes.

11. Heat Exchanger
Ensure heat exchanger is clean to provide good heat exchange.

12. Hot Water Source
Consider use of separate boiler for domestic hot water heating if domestic hot water is the only summer load for a large boiler. As a permanent or seasonal alternative consider (off-peak) electricity for DHW heating where feasible.

Cooling Systems and Heat Pumps 6

6.1 Introduction

This chapter examines two of the most common types of cooling systems found in commercial and institutional buildings: direct-expansion coolers and cold-water chillers. A typical layout for each type of cooling system is examined and opportunities for low capital cost or maintenance oriented energy savings are highlighted and described. High-cost improvements involving long-term paybacks are not addressed.

This chapter need not be read from beginning to end. Rather, select the sections most applicable to the type of cooling equipment you are responsible for. Ideally, do a walk-through of your cooling system with this chapter in hand.

6.2 Direct Expansion Cooling

Direct expansion (DX) cooling is a method of cooling air whereby liquid refrigerant is introduced directly into a cooling coil located within the air handling unit. The refrigerant evaporates (expands) in the coil and returns to the compressor by suction.

The refrigerant is compressed to a higher-pressure gas and piped to a condenser. The walls of the condenser are cooled by water or air so that the refrigerant gas is cooled below its dewpoint and is liquified. The liquid refrigerant is then returned to the cooling coil.

A receiver located between the condenser and the cooling coil contains a refrigerant charge capable of handling a large variation in the cooling load.

Direct-expansion cooling systems range in size from centralized systems capable of serving a large building to small window-type units (window air conditioner). In some designs, the refrigerant valving can be switched to interchange the function of the condenser and evaporator. The unit can then function as a heat pump providing either heating or cooling on demand.

This section addresses energy management activities for direct expansion coolers in two categories:

- centralized Direct Expansion Cooling Systems
- window and Wall Direct Expansion Cooling Units

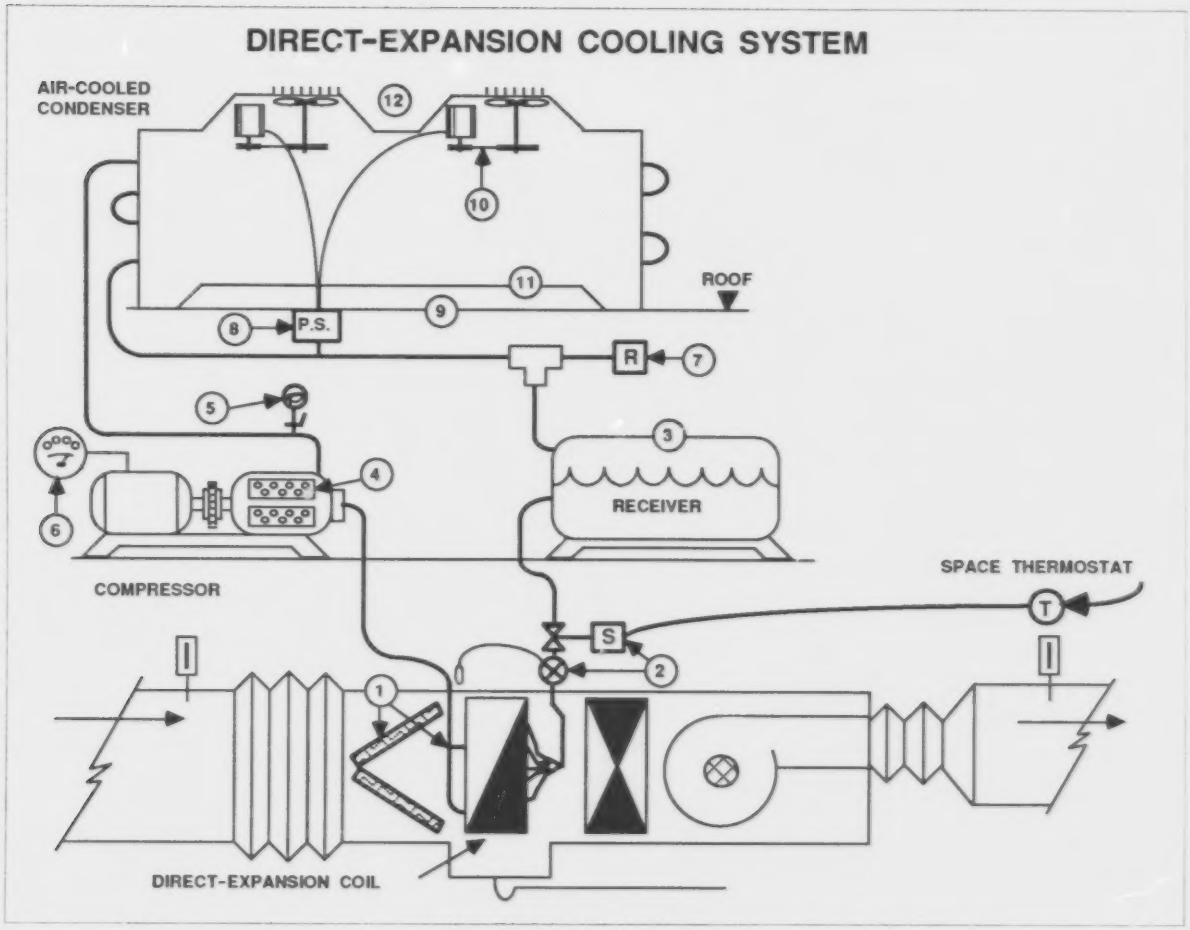
6.2.1 Centralized Direct-expansion Systems

A schematic of a typical centralized direct-expansion cooling system is provided in Figure 6.1. The energy management measures described below refer to the numbers marked on the system schematic.

1. Direct-expansion Coil
To improve refrigerating efficiency make sure filters and coils are always clean. Inspect on a monthly basis.

2. Expansion Valve
To improve the refrigerating cycle, adjust the expansion valve to give the highest evaporating temperature compatible with the required cooling load and coil sizing. (A leaking valve can be indicated by compressor short cycling.) Obtain expert advice if necessary.

Figure 6.1



3. Refrigerant

Regularly check the refrigerant charge. Lack of refrigerant causes low suction pressure and increases the energy consumption of the compressor. It is usually manifested by a warm liquid line.

4. Compressor Operation

Shut down the refrigerating system during unoccupied periods. An exception to this recommendation is that systems should not be shut down during exceptionally hot periods as "catching up" with the cooling requirement may be difficult.

If the cooling system is shut down on a seasonal basis, turn off the crankcase heater. **Note:** the heater should provide 24 hour preheating before the compressor is started up at the beginning of a season.

5. Condenser

Over time the condenser may be subject to fouling or corrosion from moisture in the system. Fouling and corrosion of the condenser is usually indicated by a rise in head pressure, assuming a constant load. A log of condenser pressure and cooling load should be maintained. Readings should be taken on a monthly basis.

6. Energy Consumption
Make a monthly record of electrical consumption. Compare current use with the historical use of electricity (kWh and kW). Variances in use should be reconciled to weather, cooling loads and equipment performance.

7. Condenser Pressure Regulating Valve
Set pressure-regulating valve to the lowest pressure needed to operate system to reduce condenser flooding.

8. Pressure Switch
Excessive head pressure can increase the load on the compressor and thereby influence energy consumption. Periodically check the pressure switch to ensure it is set to the proper setting for your system.

9. Roof Condensers
Use light-coloured gravel on roof deck near the condensing equipment. This will reduce radiant heat gain to the condenser unit from the roof area and improve cooling efficiency of the condenser.

10. Condenser Fan
An improper belt tension on the condenser fan will affect the cooling effiency of the fan and the amount of time it must operate. Fan energy consumption is optimized when the proper belt tension is maintained.

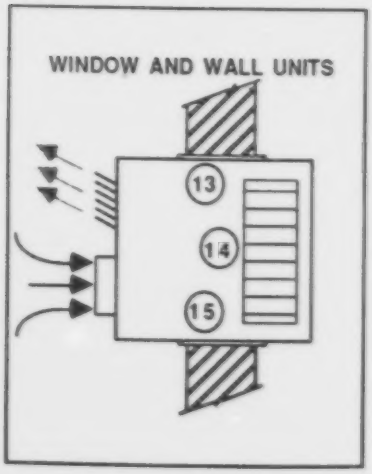
11. Condenser Cooling Fins
Clean and comb fins in the spring before startup.

12. Water Sprays in Condenser
Consider installing water sprays to reduce head pressure in hot weather (for heavily used systems). Spraying the condenser surface increases the efficiency of the condensing process. Seek professional advice before attempting this measure.

6.2.2 Window and Wall Direct Expansion Cooling Units

13. Seasonal Shutdown
Close fresh air damper at the end of the cooling period. Remove unit prior to the heating period, if possible, or install air barrier (polyethylene) on the interior side of the unit.

Figure 6.2



14. Filters, Cooling Coil and Condenser Coil
Clean all components on a regular basis to maintain optimum operating efficiency. Also, clean and comb fins in the spring before startup.

15. Unit Operation
Turn off unit during unoccupied periods (housekeeper may do this if necessary).

6.3 Chilled Water Cooling

Cooling with chilled water is a cooling method used in large buildings or in a central cooling plant that serves a group of buildings. Figure 6.3 provides a schematic of a typical chilled water cooling system. This type of system is briefly explained below.

Water is chilled in an evaporator, to a temperature varying from 6 to 12°C (43 to 54°F), and distributed to the building air handling units. The evaporator operates on the same principal as the direct expansion cooler where a refrigeration cycle is used to cool the water.

A refrigerant is circulated through the evaporator using a compressor (screw type, centrifugal, or recriprocating) that compresses and heats the gaseous refrigerant to approximately 60°C (140°F). This gas condenses into a liquid in the condenser. Once the refrigerant is in a liquid form, it can be reused in the evaporator.

The heat removed in the refrigeration cycle is normally rejected to a cooling tower. Water circulated at 30°C (86°F) removes heat from the chiller condenser and is in turn cooled in the cooling tower and returned to the condenser. Heat can also be rejected to an air-cooled condenser or a nearby body of water. Alternatively, it can be used in a heat recovery system.

The energy management initiatives numbered below refer to the numbers marked on the system schematic.

1. Chiller Water Temperature
Chilled water temperature should be adjusted to the highest possible temperature depending on the required cooling load.

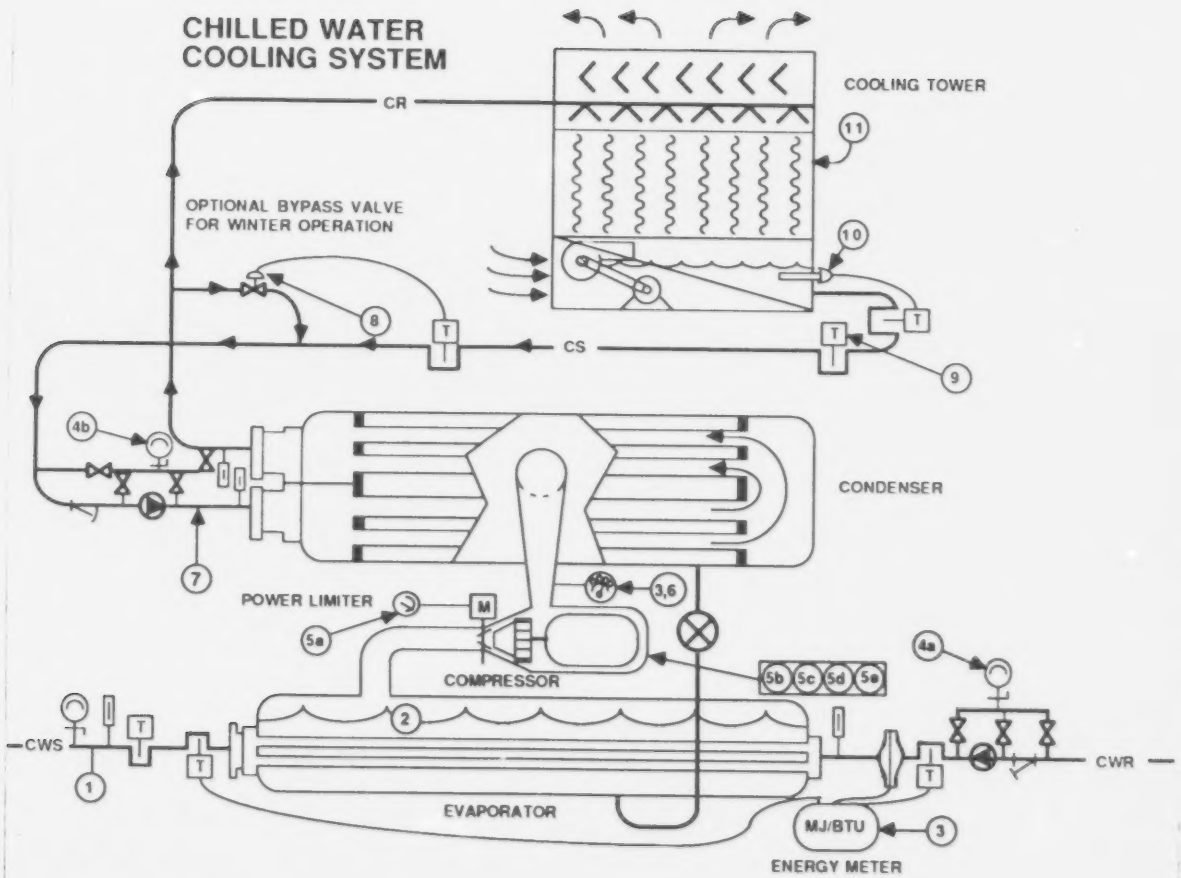
2. Refrigerant
Make sure the system is always operating with an adequate amount of refrigerant. Lack of refrigerant causes low suction pressure. This condition increases the energy consumption of the compressor. Refrigerant charge should be checked on a regular basis.

When using an R-11 refrigerant, analyze oil content in liquid refrigerant on a regular basis. Adjust to manufacturer's specifications (approx. 1 to 2%). Refrigerant checks should be performed twice a year (minimum). Normally checks are made at system startup in spring and shutdown in fall.

3. Energy Metering
Install energy meters on units of 100kW (100 tons or more) to monitor chiller performance.

4. Pressure Gauge
Pressure drop of water circuit should be monitored on a regular basis. For monitoring, the best arrangement involves installing only one pressure gauge with valving. Pressure drop is an indicator of fouling in tubes which will increase energy use of chiller.

Figure 6.3



5. Chiller/Compressor

5a. Chiller Operation

If your utility imposes peak demand charges, avoid running the chiller at full load during electrical peak periods of the month by using a power limiter. Start chiller early in the morning and precool the building below requirements. Then run the chiller at part load during the period of peak electrical demand, allowing building temperature to slowly drift upward.

5b. Seasonal Operation

Turn off chiller and pumps during unoccupied periods, except during very hot weather.

5c. Power Factor
If penalties are paid on electricity bills because of poor power factor, or demand is measured in kVA, have suppliers or consultant evaluate cost effectiveness of installing capacitors.

5d. Crankcase Heaters
To reduce heat losses during seasonal shutdown turn off crankcase heaters during shutdown seasons. **Note**: a 24-hour preheating period is required before chiller startup.

5e. Winter Chiller Operation
If the chiller must operate in winter, it is worthwhile to undertake a study to analyze the free cooling operation of the chiller. Even a conventional chiller may make use of free cooling. Alternatively, use of the water tower as a chiller in the winter period should be considered. Divert the chilled condenser water through a cooling coil(s) in an air-conditioning unit.

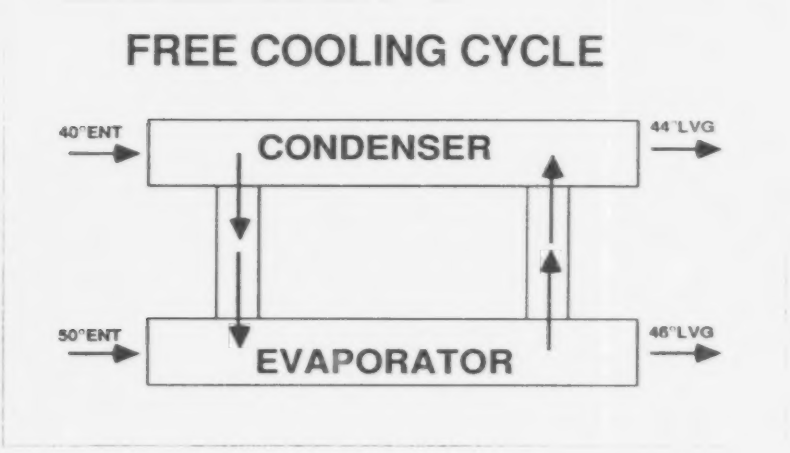


Figure 6.4

6. Electrical Meter
Install an electrical meter and monitor energy performance on a regular basis. See Chapter 3, "Operations and Maintenance", for a discussion of operating logs.

7. Refrigerant and Water Pressure
Keep a record of the refrigerant discharge pressure and condenser water pressure drop to identify progressive fouling of the condenser.

8. Bypass Valve
If a bypass valve is present in the system, adjust the bypass valve operation to lowest acceptable temperature for your condenser water.

9. Condenser Water Temperature Control
Drop condenser water temperature as low as is acceptable for the chiller type and make.

10. Cooling Tower Water Heater

If the cooling tower is equipped with a water heater, adjust setpoint of water temperature to the lowest acceptable temperature — say 5°C (42°F) just above freezing. This will reduce excessive heating of the water in the tower. Check for faulty operation during cooling periods (i.e. not on when water is 27°C (80°F).

11. Cooling Tower

On a regular basis, check the cooling tower for the following indications of poor performance.

- Clogged-up water nozzles: clean nozzles.
- Uneven air distribution at face of tower: modify tower packing.
- Moist air recirculation: install baffles or diffuser to prevent recirculation.
- Maintain proper water treatment to avoid scaling and algae buildup and to prevent biological (bacterial) contamination.

6.4 Heat Pumps

A heat pump is essentially a refrigeration cycle where the heat rejected at the condenser is used for heating purposes. The total heat delivered to the condenser is the sum of the heat extracted in the evaporator and the heat from the compressor work necessary to compress the refrigerant.

The heat pump must have a source of heat to be cooled in order to work. In residential applications, the source of heat is usually outside air, water or the ground. In large buildings, the source of heat can be waste heat from lighting in interior building areas or heat from computers. The heating requirement must occur at the same time as the cooling requirement if the heat source is inside the building, or thermal storage must be used to transfer the heat to another time period.

The principle advantages of heat pumps are noted below.

1. Heat pumps provide lower cost heating than fossil fuels if a source of waste heat can be found.
2. With heat pumps, waste heat can be recycled within the building, thus reducing the requirement for purchased energy for heating.
3. Heat pumps can usually provide both heating and cooling.

Heat pumps (and chillers) are rated according to their coefficient of performance (COP). For heat pumps the COP is expressed by the formula:

$$COP = \frac{\text{Heat rejected from condenser}}{\text{Energy input to compresser}}$$

For chillers the COP is expressed as follows:

$$COP = \frac{\text{Heat pumped from evaporator}}{\text{Energy input to compressor}}$$

The higher the COP, the more efficient the heat pump or chiller.

The energy management measures for heat pumps in large buildings are similar to measures already discussed in the previous sections of this chapter.

Air Handling Systems 7

7.1 Introduction

Air handling systems consist of an air handling unit and distribution equipment such as ductwork, dampers and air diffusers. Figure 7.1 provides a schematic incorporating many of the common components for an air handling system. In Figure 7.1 a thermostat regulates a system of dampers, a heating coil and a cooling coil. Another controller monitors humidity level and activates a spray humidifier as required.

The term air handling unit refers to a ventilation device that, when installed in a building, may serve a number of purposes:

- providing an airflow with adequate pressure and speed to reach all areas served by the unit;
- filtering and conditioning the air with cooling, heating, humidification, and dehumidification processes; and
- mixing a measured quantity of fresh outside air with recirculated air.

A typical air handling unit may contain some or all of the following components:

- fan(s);
- filters;
- heating, cooling, and dehumidification coils;
- humidifier;
- dampers to control the direction of the airflow and the mixing of outside and recirculated air; and
- control devices to regulate temperature and humidity of the airflow.

Air handling systems can be divided into two categories: air distribution and air exhaust systems. This chapter discusses measures common to both types of systems in Section 7.2. Section 7.3 discusses measures that relate specifically to distribution systems, and Section 7.4 refers to exhaust systems.

7.2 General Measures

The measures identified in the text below refer directly to the numbered components on the air handling schematic in Figure 7.1.

Low-cost Improvements

1. Damper Retrofit
If the inlet and outlet dampers on a system are in a parallel blade configuration, consider a conversion to opposed blade operation. Opposed blade dampers provide better control of air flows and usually provide less leakage in the closed position. Also, install damper edge and side seals to reduce air leakage.

Maintenance

2. On/Off Operation
Shut down the air-handling units when their service zones are going to be unoccupied for extended periods of time (overnight). If the unit provides space heating during unoccupied periods, install a thermostat control (perhaps a setback control) that will restart the unit if the temperature drops below a set temperature. During these unoccupied periods, adjust the system so that only recirculated air is used when the system is operating.

3. Heating/Cooling Systems
System operating controls should be set to ensure that simultaneous operation of heating and cooling coils does not occur.

4. Cooling Coils
Clogged or dirty coils will reduce cooling efficiency and will place a heavier load on the cooling system. Lower than normal chilled water temperature or low evaporating temperature (for direct expansion coils) will be needed to provide the required amount of cooling. This in turn increases the power requirements of the cooling system. To maintain efficiency, keep surfaces clean on the air side. On the water side, maintain proper water treatment to prevent scaling.

5. Heating System (Summer Operation)
To prevent operation of the heating system during the summer, turn off the heating coils. During the summer heating coils can be shut off and the temperature of the supply air can be controlled by a return air sensor. (Zones covered in 7.2.)

Before adjusting thermostats to their summer setpoints make sure heating coils (or baseboard heaters) are turned off.

6. Humidifier
Humidity sensors are rarely reliable. Measure humidity level in the area serviced by the system with an accurate instrument (sling psychrometer) and adjust control setpoint or service the humidity sensor when required. Install a high-limit humidistat in the supply duct work to avoid condensation.

Note: to be accurate, sling psychrometers must use distilled water and the cloth sleeve over the wet bulb should be replaced on a frequent basis.

7. Ducting
Air leakage in the air distribution/collection ducting can reduce the air handling and the heating/cooling performance of an air handling system. Inspect the duct system once or twice a year for possible air leakage at poor duct joints, torn flexible connections and leaky inspection doors. Repair or replace all leaky components.

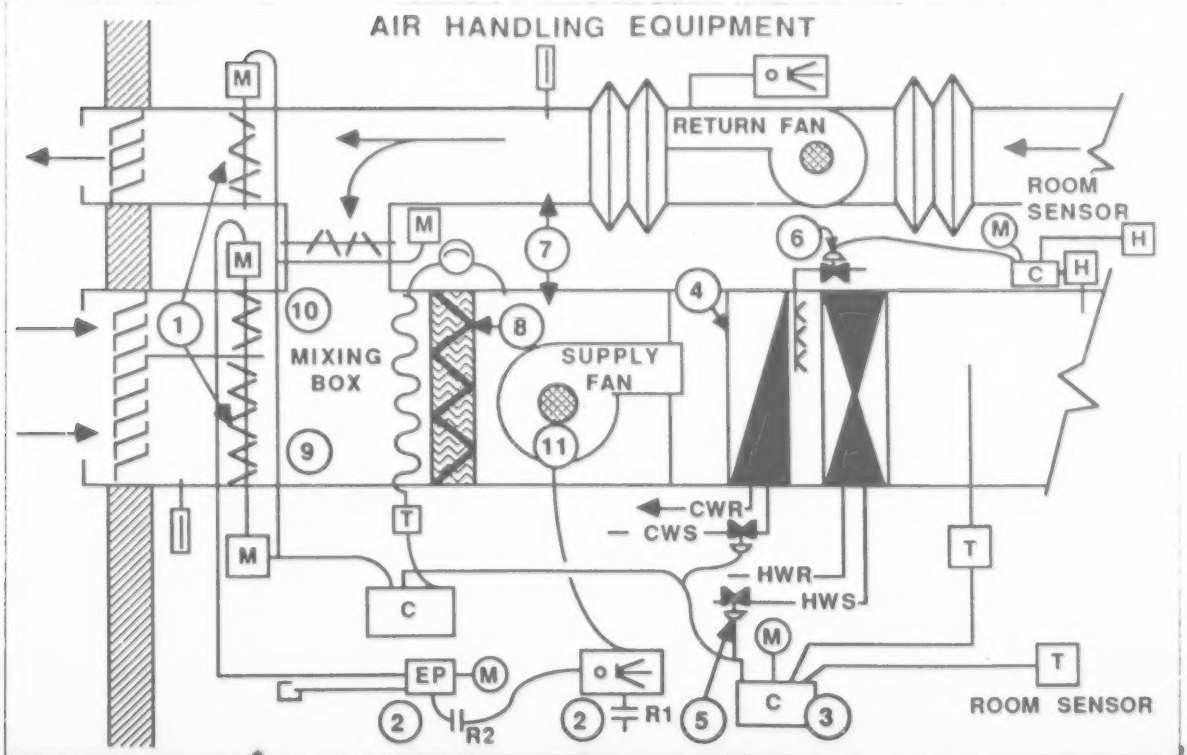
8. Filters
Filters should be cleaned on a regular basis. Clogged or dirty filters reduce the effectiveness of the air distribution system and increase operating power requirement.

9. Fresh Air Inlet Dampers
Check fresh air dampers monthly to ensure that they seal tightly in the off position.

10. Fresh Air Inlet
Whenever a change occurs in tenant load or in long-term occupancy levels have a qualified technician recalculate fresh-air requirements. The fresh air inlet dampers should be adjusted to provide a minimum amount of fresh outside air to the air handling system. See discussion on air quality in Chapter 8.

11. High-pressure Systems
On high-pressure systems (more than 1 kPa /4" w.g.) adjust the fan speed or inlet vanes on fans to optimum static pressure. Optimum static pressure in the system will be governed by the static pressure required at furthest run of the air distribution ductwork.

Figure 7.1



7.3 Air Distribution Systems

From an energy management point of view, air distribution systems can be divided into six groups:

- Dual Duct and Multizone Systems
- Terminal Reheat Systems
- 100% Air Makeup Systems
- Constant Volume - Variable Temperature Systems
- Variable Volume Systems
- Induction Systems

To ensure proper performance it is necessary to balance the system. New types of diffusers are available with variable air volume adjustments. These can be used to control individual locations. It is sometimes useful to investigate the feasibility of closed-loop heat pump systems as a major retrofit measure, but this requires expert assistance.

The balance of this section describes each of these types of distribution systems and examines specific energy management initiatives applicable to each system.

7.3.1 Dual Duct and Multizone Systems

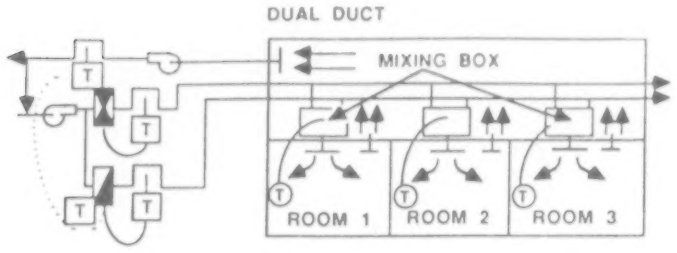


Figure 7.2

In a dual duct system, air is supplied to the building in two parallel ducts. One duct carries cold air at approximately 13°C (55°F) all year round. This duct is usually called the "cold deck".

The air in the second duct is maintained at temperatures ranging from 32°C to 50°C (90°F to 122°F). The temperature of the air in this duct is increased as the outside temperature drops. This duct is usually called the "hot deck".

Most air-handling systems previously installed in medium-sized and large-sized buildings are dual duct systems. The area serviced by the system generally divided into 2 to 15 zones. Each controlled area or zone is equipped with a mixing box where the mixture of hot and cold air is controlled by the room thermostat so as to maintain comfort.

In a multizone system, air from the hot and cold decks is mixed in the unit and carried to the zone in one duct.

Three energy management measures that relate specifically to these types of system are discussed below.

1. In Summer, Flush Building at Night
If the building is unoccupied at night during the cooling season set the system to 100% outside air. This will precool the building for the next occupancy period. The system should be set up to operate in this mode whenever outdoor temperature is 2°C (4°F) or more below the room temperature, when the outside humidity is not excessive.

2. Seasonal Adjustments
The temperatures of the hot deck and the cold deck can be adjusted according to the seasonal heating/cooling load. The temperature set points for both duct systems should be as close as possible to room temperature while maintaining comfort in all building spaces (discriminator control). A discriminator control will sense the peak zone heating and cooling needs and reset hot deck and cold deck temperatures to their lowest and highest temperatures respectively.

3. Heating System (summer)
During the summer, when room temperature is not critical, turn off heating coil and control cold deck temperature with return air sensor. Do not use hot deck until room air temperature falls below 20°C (68°F).

7.3.2 Terminal Reheat System

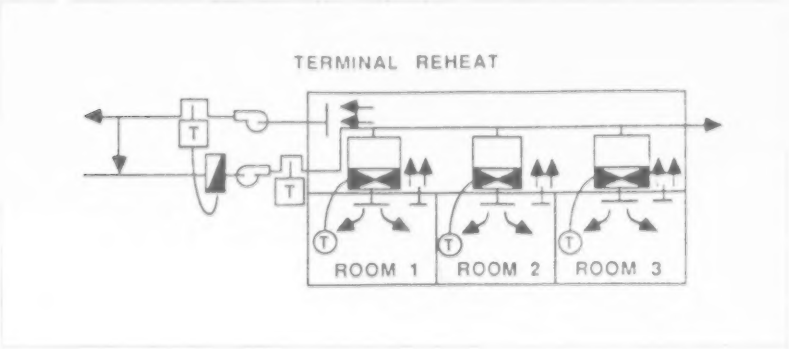


Figure 7.3

With this type of system, air is supplied to the rooms at a constant temperature of 13°C (55°F). If the temperature of the room drops below a set temperature (setpoint), a thermostat will activate a reheat coil in the supply air ducting. This system is commonly used in offices and hospital buildings.

Two energy management measures relating specifically to this type of system are discussed below.

1. Seasonal Adjustment of Reheat Control
The air supply temperature can be reset on a seasonal basis (or more frequently) to bring setpoint as close as possible to room temperature and maintain comfort. A discriminator control can be used to reset supply air temperature as high as possible and reduce reheating of the supply air.

2. Shut Down Reheat Coils in Summer
In summer, when room temperature is not critical, turn off reheat coils and control cooling coil with a return air sensor. Do not provide reheat until room air temperature falls below 20°C (68°F). Consider elimination of reheat coils for all interior space served by system and air balance system to achieve comfort in all spaces. Obtain professional advice before proceeding with this measure.

7.3.3 100% Outside Air Systems

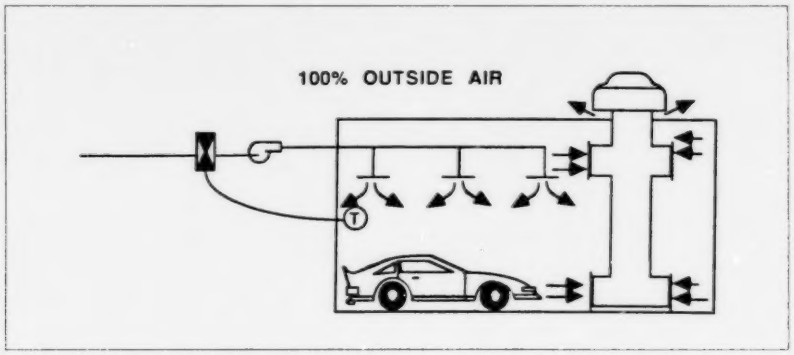


Figure 7.4

These systems are generally designed as makeup air units. The air introduced by this type of system is designed to compensate for air volumes exhausted by kitchen hoods, spray booths, or other shop equipment.

Conditioning of the incoming air is generally limited to heating. A room thermostat generally controls the amount of heat required to maintain room comfort.

Three energy management measures related specifically to this type of system are discussed below.

1. Reducing the Heating Requirement
To reduce the heating requirement for this type of system, it is recommended that the system be shut down during unoccupied periods (add recirculation if system is used for heating purposes). Also, consider reduction of the volume of fresh air brought in by the system and/or reducing exhaust volume required.

Note: If heating is provided by a liquid based system avoid freeze-up of coil when system is stopped or restarted.

2. System Operation
Limit the operation of the exhaust and supply using:

- timer switches (hoods, spray booth, welding bench);
- carbon monoxide detector (garage and interior parking);
- occupancy detectors (shower rooms).

3. Utilizing Heat Recovery
If system operates more than 90 hours/week, consider incorporating a heat recovery device that uses exhaust air to preheat fresh incoming air. Process heat may also be available for heat recovery applications.

7.3.4 Constant Volume - Variable Temperature Systems

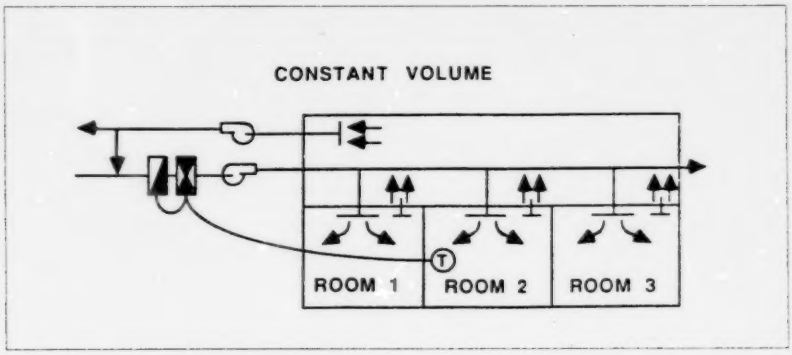


Figure 7.5

These type of systems are designed to service a small area such as an auditorium, gymnasium or conference room. Full air-conditioning features can also be incorporated into this type of system. A room thermostat generally controls the operation of the heating and cooling equipment.

Two energy management measures that relate specifically to this type of system are discussed below.

1. Calibrate Thermostats
Check thermostat to make sure heating and cooling setpoints are respectively 20°C (68°F) and 26°C (78°F) with a dead band in between the two setpoints.

2. Heating (Summer Operation)
Where possible, turn off the heating coil during the summer period.

7.3.5 Variable Air Volume Systems (VAV)

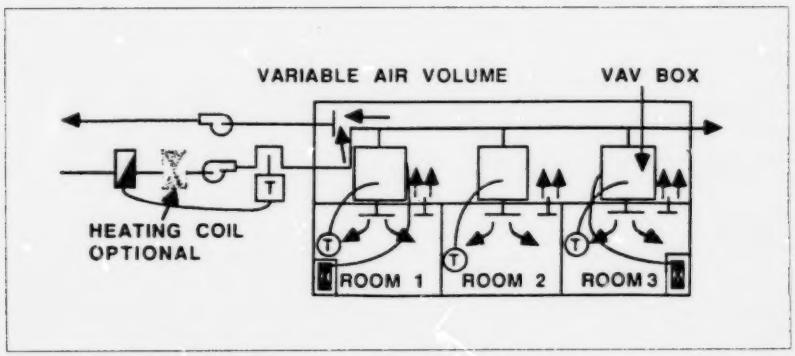


Figure 7.6

This type of system is much like a terminal reheat system except that the room thermostat not only controls the heating function but also can modulate the air volume supplied. In the control sequence, the cool air is first reduced to a minimum before heating is activated. VAV systems are commonly used in office buildings.

Three energy management measures related specifically to this type of system are discussed below.

1. Heating (Summer Operation)
During the summer, turn off baseboard heaters and/or reheat coils. During the rest of the year, for systems with hot water heating, the hot water supply temperature should periodically be readjusted to conform to the exact heating demand of the building.

2. Reset Supply Air Temperature (Winter Operation)
For areas of the building requiring additional heat (for example perimeter or corner rooms) the supply air temperature can be reset upwards in winter months to increase air circulation and reduce reheat requirements.

3. Variable Volume Control
Consider installing a two-speed motor or a frequency inverter for an existing motor. Obtain professional assistance before proceeding with this measure.

7.3.6 Induction Air Handling Systems

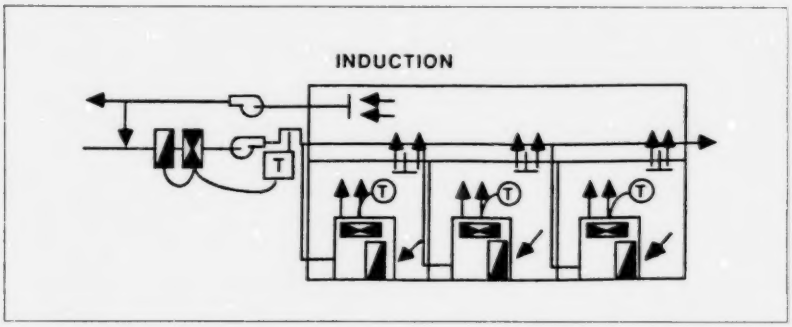


Figure 7.7

Induction systems are named for the induction effect provided when air supplied to the room, called primary air, serves to induce air motion within the room. The mixture of primary air and induced room air is then conditioned by the heating and cooling coils located within a cabinet installed in the room. A room thermostat controls in sequence the cooling and heating coils.

Six energy management measures that are related specifically to this type of system are discussed below.

1. Fresh Air Requirements
Calibrate fresh air portion of primary air to meet actual building occupancy. Consider diversion of outside air to interior air systems providing building has common return air for interior and induction system.

The portion of fresh air delivered to each induction unit must be in accordance with the fresh air requirements of each particular area (based on occupancy or use). Obtain professional assistance before proceeding with this measure.

2. Thermostat Setting
Check room thermostats to make sure heating and cooling setpoints are respectively 20°C (68°F) and 26°C (78°F). There should be a operational dead band between the two setpoints.

3. Minimize Conditioning of Primary Air
During the winter, to minimize the need to heat primary air, the air should be delivered to the induction units at a temperature of 10°C to 12°C (50°F to 54°F).

During the summer primary air should be cooled as little as possible. If the induction units used in the system are not drained the primary air should be cooled (dehumidified) to avoid condensation in the induction units.

4. Adjustment of Heating/Cooling Coil Temperatures
Adjust heating/cooling supply temperature monthly to reduce differential between water temperature and room temperature.

5. Convection Heating
Use convection heating during setback periods. The heating coils in the conduction units will work as radiators with the primary air fans off. The hot water temperature should be scheduled according to heating demands in unoccupied periods.

Note: This measure may not be possible with electric heating coils if coils overheat.

6. Two-speed Fans
Consider two-speed motors for the induction unit supply/return fans or frequency inverters for existing motors. Induction systems will typically operate on low speed for 80% of all operating hours. Obtain professional assistance before proceeding with this measure!

7.4 Air Exhaust Systems

Air exhaust systems are designed to expel contaminated air. Some examples of the most frequently exhausted contaminants are listed below:

- odorous gases (washrooms, storage rooms);
- smoke (conference room, welding shop);
- cooking odours (kitchen);
- carbon monoxide (garage);
- carbon dioxide (office when levels exceed 1,500 PPM);
- solvents (spray booths);
- high humidity areas (swimming pools); and
- high temperature areas (boiler room, electrical room).

The components of an air exhaust system include an exhaust fan, ductwork and grilles, and hoods to capture contaminated air as close as possible to the source. In addition most exhaust systems incorporate a series of controls to regulate the operation of the fan and its accessories, such as a motorized damper.

Energy management action for exhaust systems will depend in part on the area being exhausted. The first part of this section describes more general measures applicable to all exhaust systems. The balance of this section examines a number of different exhaust applications and describes specific energy management initiatives applicable to each system.

7.4.1 General Exhaust System Energy Management Measures

Specific measures are noted below. In addition, it is often useful to consider heat recovery for high exhaust areas.

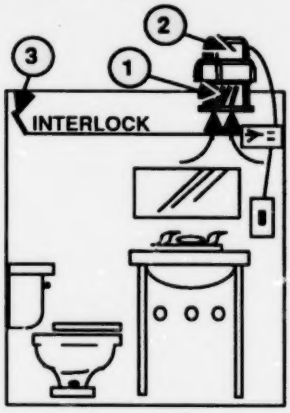
1. Prevent Gravity Exfiltration

Most exhaust fans are at roof level. Vertical ductwork creates a chimney that induces gravity exfiltration when an exhaust fan is turned off. The addition of a motorized backdraft damper at the outlet will greatly reduce this loss. Locate the damper at the building skin or as close to it as possible to avoid transmission losses as well.

2. Adjust Airflow With Change in Use

If the building has undergone major changes to tenant loads or work loads, have a qualified person recalculate exhaust air requirements.

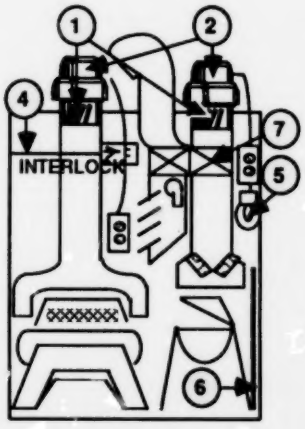
7.4.2 Washrooms



3. Interlock Exhaust Air with Main System
The operation of washroom exhaust fans should be interlocked with the operating control of the main air handling system. When the main system is turned off during unoccupied periods the exhaust system will also automatically shut off.

Exhaust fans can be turned off simultaneously with the main air handling system. Consider air balance of the building when scheduling fan systems since exhaust fans will force the building into negative pressure if they are left running after ventilation systems are turned off.

7.4.3 Kitchens



4. Interlock Dishwasher Exhaust
Interlock the on/off control for the dishwasher with the booster and exhaust fan to ensure use is coincident with dishwasher operation.

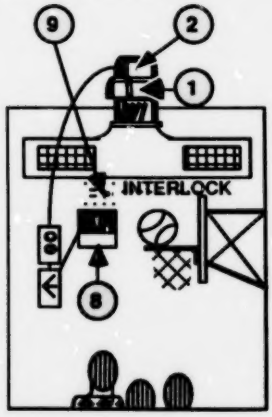
5. Operate Exhaust According to Use
Turn off the exhaust system after cooking hours.

6. Modifying Exhaust Hood
Exhaust airflows can be reduced if panels are installed on the unattended and open sides of the exhaust hood. This will allow a reduction of the required exhaust airflow of up to 50% for most applications.

Note: Ensure that an air velocity of at least 7.6 metres per second (1,500 feet per minute) is maintained in all portions of the exhaust ductwork.

7. Heat Recovery
If the hoods are in operation over 4,000 hours per year, it is probably worthwhile to consider installing a heat recovery device on the exhaust air.

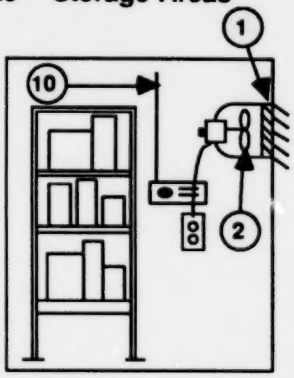
7.4.4 Gymnasium



8. Operate Exhaust According to Occupancy
To ensure the exhaust fan only operates when the gym is occupied have the on/off control of the exhaust fan operate off an occupancy detector.

9. Interlock Exhaust With Ventilation System
Another way of ensuring that the exhaust fan does not operate during unoccupied periods is to interlock the on/off control of the exhaust fan with control of the main ventilation system.

7.4.5 Storage Areas

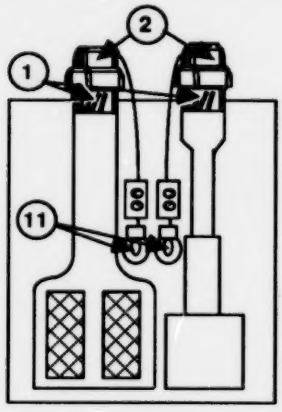


10. Reduce Air Exhausting

Operate the exhaust fan on a duty cycle. For example, the fan could be operated for one hour, then turned off for two hours.

Another approach is to reduce the exhaust airflow to meet the absolute minimum requirements of local codes.

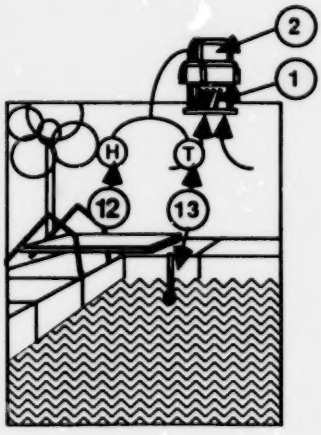
7.4.6 Shop Areas



11. Reduce Exhaust Operating Time

Install a timer switch to replace manual pushbutton on/off switch.

7.4.7 Swimming Pools



12. Optimize Humidity Level

Given the temperatures common in a swimming pool area, and the large surfaces of pool water exposed, it is generally not worth dehumidifying a pool area below 60% relative humidity. Below 60% RH, moisture evaporation off the pool surface will replace moisture in the air almost as fast as it is exhausted. As a result the exhaust fan on/off control should be operated by a dehumidistat control set at 60% RH. Ensure the dehumidistat is calibrated frequently.

Consider the use of dehumidification equipment for large pools to recover waste heat. Obtain professional advice before proceeding with this measure.

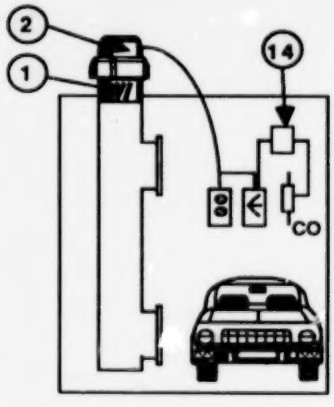
13. Optimize Air/Water Temperature

The pool water temperature should be maintained below air temperature to minimize evaporation. Water temperature should be no more than 26°C (79°F). Air temperature should be at least 10°C (18°F) above water temperature.

Pool Covers

Consider using a pool cover during unoccupied periods to eliminate evaporation of moisture from the pool surface. This will reduce exhaust fan operation time, and also reduce the need for heated makeup air to replace exhausted air. This measure is practical if pool is unoccupied for more than one-third of the time.

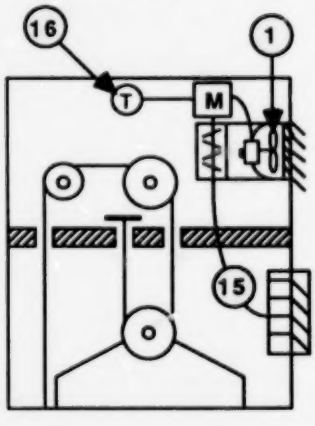
7.4.8 Garages



14. Control Operation With Carbon Monoxide (CO) Detector

To make the exhaust more responsive to safety requirements and to ensure the exhaust system operates only when necessary, replace manual switching of exhaust system with an automatic control by a carbon monoxide (CO) sensor. One or more sensors should be located in centralized areas.

7.4.9 Elevators



15. Stop Air Leakage

To avoid air leakage created by the stack effect of the elevator shaft keep all openings airtight at top of elevator shaft and elevator penthouse.

Note: The degree of airsealing or other air tightening measures may be affected by local codes.

16. Temperature Control

Operate exhaust fan in equipment room from a thermostat set to the highest acceptable temperature. The thermostat setting should be above the normal space heating temperature for the building. If the thermostat setting is below building temperature, the exhaust fan will run continuously.

7.5 Heat Recovery Devices

Heat recovery potential is present in most air handling systems. However, the use of the recovered heat by a system must be economically justifiable. Return of the recovered heat to the process from which it came should be the first priority since such systems usually require less control and are less expensive to install.

With all heat recovery devices, on-going effectiveness of the heat transfer surfaces and maintenance requirements should be a primary consideration. Actual payback on the initial investment may be substantially affected by deterioration in performance due to fouling of transfer surfaces or high maintenance costs.

Air-to-air heat recovery devices are applied over a wide temperature range and consist of the following types:

- plate,
- rotary heat wheel (see Figure 7.8),
- run-around loop (see Figure 7.8),
- heat pipe (see Figure 7.9), and
- recuperator.

For general retrofit applications, particularly where recovered heat will be used elsewhere or where multiple exhaust and use points exist, the run-around loop offers many advantages. Although the efficiency of recovery is generally lower, the need to bring two air streams to a common device is eliminated.

Plate exchangers offer a relatively high efficiency with a low possibility of cross-contamination. Rotary heat wheels offer high-efficiency, simple-capacity control and moisture recovery if desirable, with some cross-contamination. Heat pipes offer high efficiency, no cross-contamination and no moving parts, but they involve higher cost and reduced efficiency when the receiving end of the heat pipe becomes fouled.

A recuperator is an air-to-air device used to transfer heat from a high-temperature furnace exhaust to the combustion air. These are usually somewhat less efficient than other devices but are built to withstand the high temperatures exhausted from fired equipment. Application of such devices must consider the existing combustion control system for regulating fuel-to-air ratio since preheating combustion air will substantially change its density. Air metering must be done prior to the preheat or it must compensate for the density change. Obviously, a large rise in the combustion air temperature will also require specially designed burners.

Figure 7.8

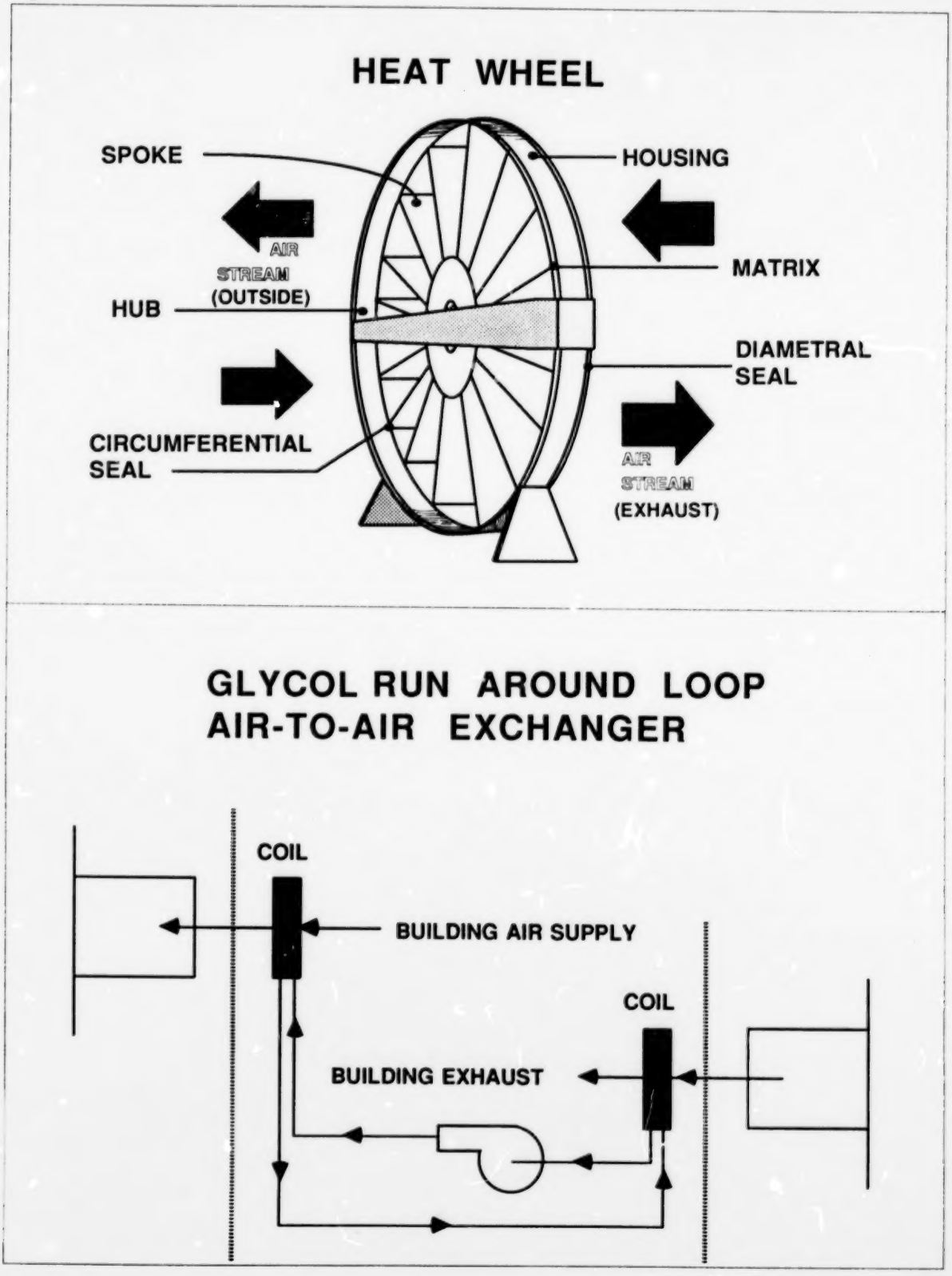
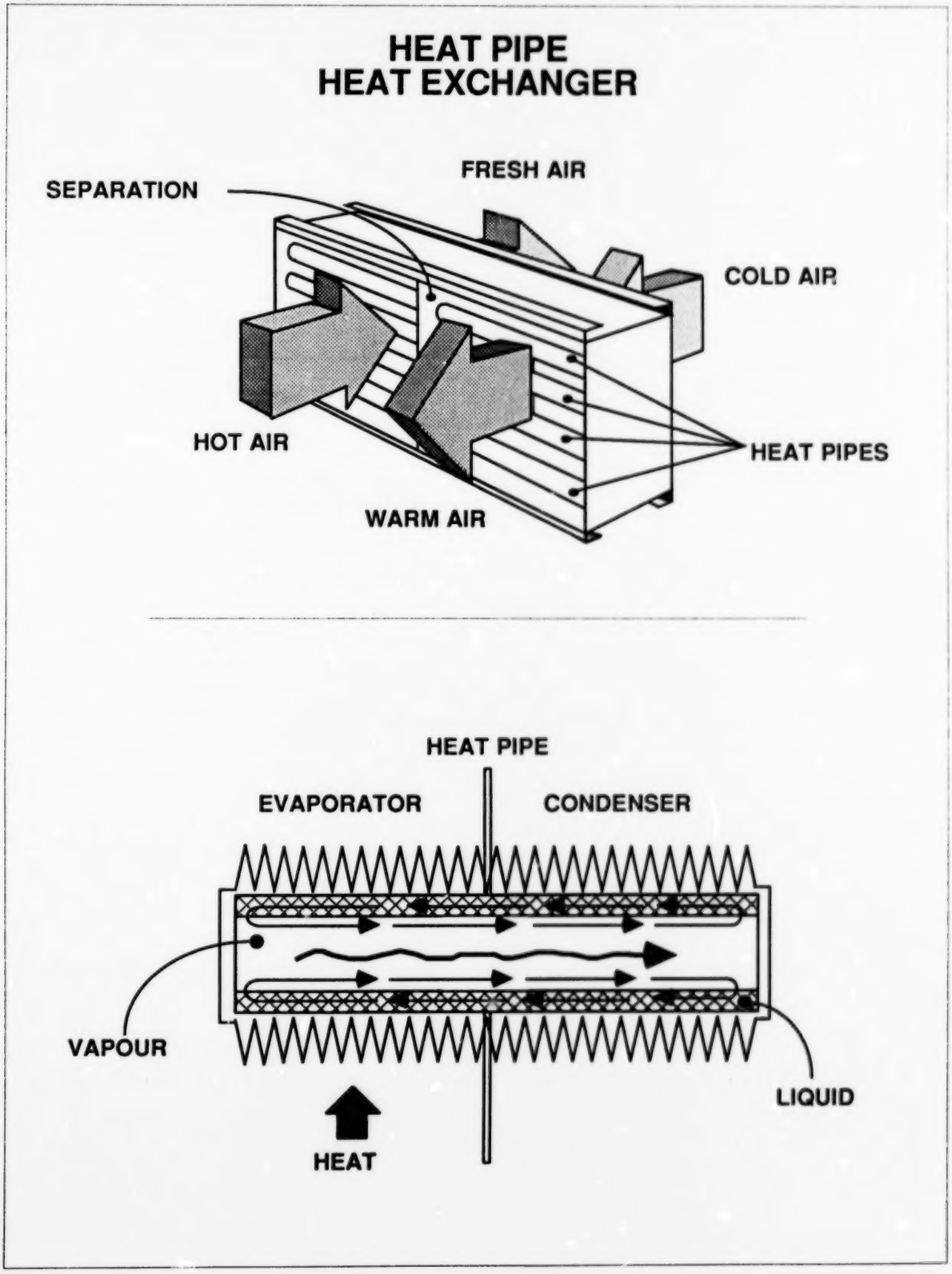

HEAT WHEEL
SPOKE
HOUSING
AIR
STREAM
(OUTSIDE)
MATRIX
HUB
DIAMETRAL
SEAL
CIRCUMFERENTIAL
SEAL
AIR
STREAM
(EXHAUST)
GLYCOL RUN AROUND LOOP
AIR-TO-AIR EXCHANGER
COIL
BUILDING AIR SUPPLY
COIL
BUILDING EXHAUST

Figure 7.9


HEAT PIPE
HEAT EXCHANGER
SEPARATION
FRESH AIR
COLD AIR
HOT AIR
HEAT PIPES
WARM AIR
HEAT PIPE
EVAPORATOR
CONDENSER
VAPOUR
LIQUID
HEAT

8.1 Introduction

The air quality issue in modern buildings has developed into a significant concern for today's building manager and operator. The public now has greater awareness of health related concerns and there is increased research documenting these issues. On the other hand, heating and cooling systems that use excess fresh air also require more energy. To compound this problem there is no single, accurate method of measuring air quality, and solutions to air quality problems tend to be building- and site-specific.

The challenge to building managers is to find the optimum levels of fresh air to maintain comfort conditions. **Good air quality and energy conservation should be complementary.** One should not be achieved at the expense of the other.

This chapter will provide an overview of the factors affecting air quality, a discussion of current guidelines and notes on troubleshooting procedures and air quality control strategies.

8.2 The Air Quality Issue

Air quality is a complex issue that affects:

- occupant comfort, health and productivity, and
- acceptance of energy conservation measures

Comfort, Health and Productivity

Common symptoms that may be due to poor air quality are tiredness, dizziness, nausea, headaches, inability to concentrate, irritation of eyes, nose and throat or of the respiratory tract, skin irritation and lethargy, faintness and irritability. However, these symptoms should not automatically be linked to poor air quality. Various types of stress can also produce similar symptoms.

Air quality involves both health issues and comfort issues, and it is often difficult to distinguish between the two. Initial symptoms due to some contaminants may be relatively mild and perceived as a comfort problem while long-term effects can cause health problems which may lead to absenteeism and loss of productivity.

Energy Conservation

At the same time the air quality issue can affect the acceptance of existing and planned energy conservation measures where it is perceived that these measures are a direct cause of the problem. However, when we examine several trends affecting air quality in buildings we can see that the origins of the issue are considerably more complex.

8.2.1 Trends Affecting Air Quality

The fields of building construction, office automation and building heating and maintenance have changed drastically over the past thirty years. Some of the major trends that have affected air quality are:

- New Building Design And Construction
- Decreased Building Ventilation Rates
- Outside Air Quality
- Increased Indoor Exposure
- Advances In Research

Each of these trends is discussed in greater detail below.

New Building Design and Construction

Modern building materials contain many new chemicals which can give off gases or vapours such as formaldehyde and radon. Other organic and inorganic chemicals are introduced to commercial buildings through paints, solvents and photocopiers. Allergens from airborne particles and dust are also present in the commercial environment.

With the shift to year-round space conditioning, building design moved to inoperable windows since open windows could create an imbalance in the air-handling system. Commercial buildings designed today are also more energy conserving with tighter building envelopes. With no operable windows, buildings cannot rely on manually controlled natural ventilation, and tighter envelopes mean less outside air infiltration.

Decreased Ventilation Rates

HVAC designers, and also building managers in existing buildings, have reduced outside air ventilation rates to lower levels in keeping with energy conservation guidelines.

Variable-air-volume systems used in many large buildings often have decreased air circulation rates compared to conventional constant-volume systems. Air circulation rates affect the purging of local contaminants such as cigarette smoke.

Older building stock is now undergoing major retrofits to HVAC systems to reduce energy costs. HVAC ventilation fans are being modified and generally operated for fewer hours each working day. New control strategies are calling for the conversion of all "outside air" systems to recirculation type systems (where applicable) with less outside air delivered to the space.

Retrofit air sealing of older building stock is reducing the amount of infiltration available to supply fresh air to the building.

Outside Air Quality

Outside air quality has generally deteriorated in our major cities due to pollution from industrial plants, automobiles and other combustion-type processes.

Increased Indoor Exposure

A larger percentage of the work force spends their full working day in a commercial building environment. In some cases, workers can live in the same complex and not leave the commercial building structure for days or weeks.

Research Advances

In the absence of a single air quality standard, attention and concern is focused on individual contaminants as we discover the means to measure their levels and test for toxicity and exposure effects.

8.3 Air Quality Criteria and Guidelines

There is no single, accurate method of measuring air quality. While it has long been understood that fresh air is a requirement for human health, just how fresh the air should be and how much is required has been a matter of continuing study and debate.

As the issue has evolved two "working tools" have been developed as indicators of air quality. The ventilation rate as expressed in L/s (cfm) provides a measure of the amount of fresh air delivered to a space. A measure of carbon dioxide (CO_2) levels in the space is used as an indicator of the effective ventilation rate. These indicators have been used in the development of standards and guidelines for acceptable air quality.

In the absence of a single measure to indicate air quality, it is still a very subjective issue. In other words, acceptable air quality has not really been completely quantified. Rather it is highly dependent on the comfort of the individual. Comfort is dependent on several factors – all of which must be taken into account when developing criteria for acceptable air quality.

8.3.1 Indicators of Air Quality

Ventilation Rate

Natural air exchange is known to take place through infiltration and exfiltration. For many buildings this is the only form of ventilation. Other buildings rely on mechanical ventilation where a certain amount of fresh air (10-15%) is mixed with a larger amount of recirculated air.

Infiltration and ventilation rates are expressed in terms of air changes per hour (ach), i.e. the number of times per hour the outside air equivalent to the volume of space, enters the space. For airborne contaminants ventilation and infiltration rates are important parameters affecting concentration and transport of contaminants.

Carbon Dioxide (CO_2) as a Measure of Ventilation

The normal level of CO_2 present in outside air is 300 to 400 ppm. CO_2 is an inert gas and can only be removed from a building by ventilation. Therefore, CO_2 levels can be used as a general indication of the ventilation rate. A decrease in the CO_2 level is perceived when the ventilation is on full outside air mode compared to recirculation mode.

It should be noted that CO_2 is only an indicator of ventilation rates for a building and should not be used as a comprehensive air quality index.

When CO_2 rates are acceptable, real problems may still exist due to other contaminants in the air, inadequate circulation of ventilation air or poor distribution of ventilation air.

8.3.2 Standards and Guidelines

Air quality is an evolving issue. Standards and guidelines for air quality in buildings have developed along with an evolving understanding of human requirements for fresh air to support health and of the major air related contaminants and their effects.

For example, in North America minimum ventilation standards rose during the nineteenth century from 2.5 L/s (5 cfm) to 15 L/s (30 cfm). This was in response to a growing understanding of airborne diseases such as tuberculosis. As the threat of these diseases decreased, the standard has dropped in the twentieth century from 15 L/s (30 cfm) in 1905 to 2.5 L/s (5 cfm) in 1973.

The American Society of Heating Ventilation and Air Conditioning Engineers (ASHRAE) was one of the first organizations to establish guidelines for air quality. ASHRAE's research has led to the publication of minimum ventilation rates to maintain the indoor environment within a key range of guidelines. This information is presented in Figure 8.1.

Figure 8.1

Recommended Commercial Ventilation Rates

Commercial Area	Estimated Persons per 1,000 ft² Floor Area	ASHRAE 62-1973 Outdoor Required Ventilation Air per Human Occupant				ASHRAE 62-1981	
		Minimum		Recommended		Smoking	Non-Smoking
		cfm	L/s	cfm	L/s	cfm	cfm
Garages, auto repair shops, service stations							
Parking garages (enclosed)	—	1.5	7.5	2-3	10-15	1.5	1.5
Auto repair workrooms (general)	—	1.5	7.5	2-3	10-15	1.5	1.5
Theatres							
Auditoriums (no smoking)	150	5	2.5	5-10	2.5-5	35	7
Auditoriums (smoking permitted)	150	10	5	10-20	5-10	35	7
Ballrooms (public)	100	15	7.5	20-25	10-12.5	35	7
Gymnasiums and arenas							
Playing floors — minimal or no seating	70	20	10	25-30	12.5-15	—	20
Locker rooms	20	30	15	40-50	20-25	35	15
Spectator areas	150	20	10	25-30	12.5-15	35	7
Swimming pools	25	15	7.5	20-25	10-12.5	—	0.5
Iceskating, curling, and roller rinks	70	10	5	15-20	7.5-10	—	20
Transportation							
Waiting rooms	50	15	7.5	20-25	10-12.5	35	7
Ticket and baggage areas, corridors and gate areas	50	15	7.5	20-25	10-12.5	35	7
Concourses	150	10	5	15-20	7.5-10	35	7
Offices							
General office space	10	15	7.5	15-25	7.5-12.5	20	5
Conference rooms	60	25	12.5	30-40	15-20	35	7
Doctors' consultation rooms	—	10	5	10-15	7.5-10	35	7
Waiting rooms	30	10	5	15-20	7.5-10	35	7
Educational Facilities							
Classrooms	—	—	—	—	—	25	5
Laboratories	—	—	—	—	—	—	10
Libraries	—	—	—	—	—	—	5

(from B. Meyer, *Indoor Air Quality*)

No Ontario government regulations currently govern the air quality of commercial building environments. Some recent testing by officials of the Ontario Department of Labour, however, has led to guidelines for CO_2 levels in office space.

Ontario Government Guidelines for CO_2 Levels

under 600 ppm	:	No concern.
between 600 and 800 ppm	:	Some concern, especially in elevated temperatures.
between 800 and 1,000 ppm	:	Expect some complaints.
over 1,000 ppm	:	Expect routine complaints. Recommend action to reduce the level below 1,000 ppm.

Figure 8.2

For residential buildings, recent revisions to the National Building Code specify that houses be equipped with a mechanical ventilation system capable of supplying 0.5 ach (air changes per hour).

8.3.3 Criteria

While it is not possible to measure air quality by a single standard, criteria have been developed which address all aspects of the issue from the qualitative point of view of occupant comfort.

Generally comfort is perceived when physical, chemical and biological stresses are at a minimum. Quality of air and the perception of air quality can be quite different. The major components influencing each are common, and are listed below.

- Physical
  - physical contaminants in the air
- Chemical
  - chemical contaminants in the air
- Biological
  - biological contaminants in the air
- Thermodynamic Characteristics of the Air
  - air temperature
  - relative humidity, air velocity

(Each of these components of air quality is discussed in detail in the next section.)

In general terms, acceptable air quality can be defined by the following three criteria:

1. Adequate thermal condition of the air capable of providing thermal acceptability for the occupants (ASHRAE S & D 55-1981).

2. Appropriate concentration of oxygen and carbon dioxide to allow normal function of respiration for the average individual.

3. Concentration of contaminants below levels which can have deleterious effects or cause complaints by occupants.

8.4 Air Quality Components

As discussed earlier physical, chemical and biological contaminants, as well as the thermal characteristics of air, can all affect air quality.

8.4.1 Thermal Factors

Thermal factors affect the air quality issue in two ways. The human perception of air quality comfort is related to factors such as air temperature as well as to the actual composition of the air. For example, too high a temperature or lack of air movement may create a sensation of "stuffiness". Secondly, the thermal characteristics of the air will affect the actions of contaminants in the environment. For example, excessive humidity will promote the growth of micro-organisms.

A thermally acceptable environment will minimize physical stress. Thermal comfort depends on the factors listed below.

- Air temperature: the temperature set by building operation can vary considerably due to temperature stratification within the space and such variations can affect occupant comfort.
- Air velocity: air distribution systems may create the sensation of drafts or, conversely, of "stuffiness".
- Relative humidity: relative humidity expressed as a percentage varies in the range of 20% to 80% for most buildings. Relative humidity below 20% will result in discomfort for some people.
- Static electricity: static buildup can also occur with low relative humidity. Testing has shown that most people link dryness or perception of humidity level to air temperature.

In order to maintain comfort the thermal characteristics of a building should be maintained within the ranges recommended below.

Heating Season	Cooling or Summer Season
• 20-23°C (68-74°F) • 30-60% relative humidity • 0.15-0.25 m/s (30-50 ft/min) air velocity	• 20-26°C (68-79°F) • 40% relative humidity • 0.25 m/s (50 ft/min) air velocity (temperature can be raised to 28°C/83°F if air velocity is 0.8 m/s, or 160 ft/min)

Vertical temperature difference from ankle to head (in sitting position), should be less than 5°C (9°F). Temperatures above 25°C (77°F), can cause complaints of "stuffiness", "stale air" and "not enough oxygen". A reduction in air temperature will often eliminate an "air quality complaint".

8.4.2 Physical Contaminants

Some of the major physical contaminants are listed below.

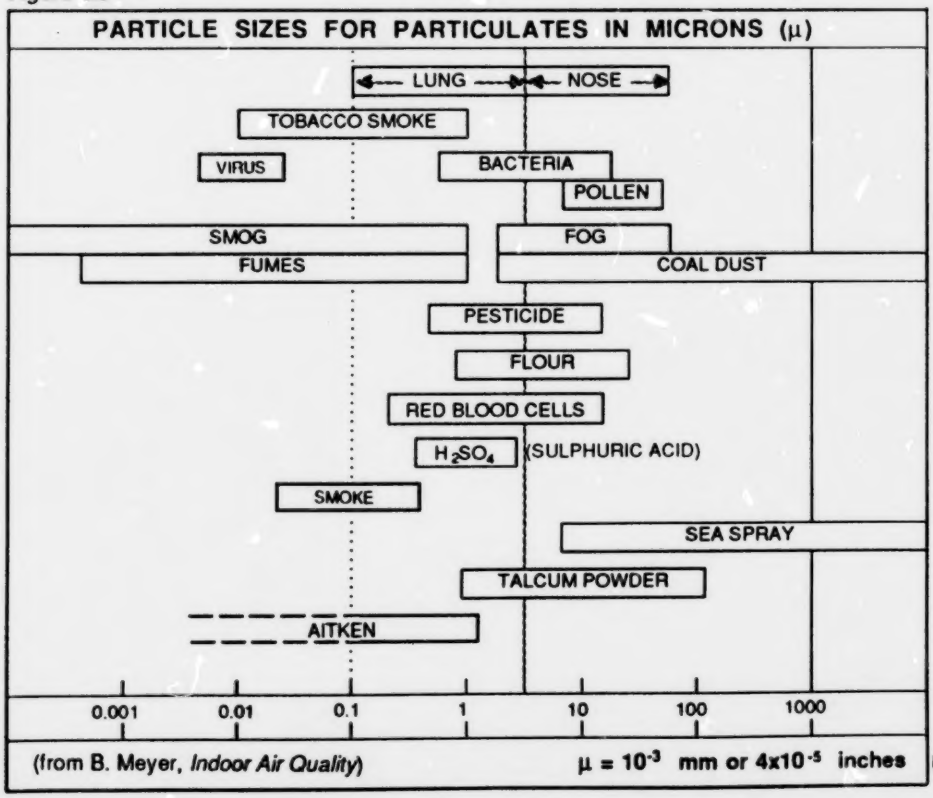
Contaminant	Source
Dust particles	Outdoor air
Tobacco smoke (particulates & vapour)	Cigarettes
Asbestos fibres	Asbestos building products
Metallic dust	Building materials
Wood particles	Building materials

The particles of smoke, dust, pollen etc., enter the indoor environment either from outside by infiltration or from activities and processes in the building. The amount of material entering the building from outdoors will depend on the wind velocity and the amount of infiltration (less if building envelope is tight, otherwise more). Particles can be generated indoors by smoking, other indoor combustion processes and existing building materials.

The sizes and shapes of particulates have a wide spectrum. Depending on the weight, these particles settle at faster or slower rates. Particles can be resuspended when local air turbulence occurs, as when a person walks by where the dust has settled.

Particles smaller than 1.5 mm (1/16") in diameter can reach the lungs; however, larger particles settle too fast to reach the nose or mouth. Figure 8.3 shows the particle sizes of various substances.

Figure 8.3



8.4.3 Chemical Contaminants

Some of the major types of chemical contaminants that may be found in a non-industrial building are listed below.

Contaminant	Source
Formaldehyde or Aldehydes	Paints, photocopiers.
Volatile Organic Compounds (Hydrocarbon solvents)	Aerosol sprays.
Ozone	Photocopiers, spray cans.
Radon & Radon Progeny	Geological, soil, ceramic
Combustion Products, CO, CO_2, SOx, NOx	Incomplete combustion, process combustion, human metabolism.

A number of chemical contaminants can be found in the indoor air of a typical office or institutional building. These include the products of combustion, namely: Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxides of Nitrogen (NOx) and Sulphur Dioxide (SO_2) These chemicals, in some concentrations, can be found in the indoor air whenever a combustion source is within the building.

Ozone concentrations can increase due to photocopiers and other sources such as aerosol spray cans. Cleaning agents can give off toxic fumes. Building materials such as paints and particleboards can add to formaldehyde and other hydrocarbon concentrations.

As the note below indicates, even exhaled human air is a source of a wide variety of contaminants.

* Volatile Components in Exhaled Human Air

Exhaled air contains:
carbon dioxide, ammonia, carbon monoxide, acetone, acetaldehyde, acetic acid, acetonitrile, acetylcholine, alanine, butyraldehyde, creatinine, diethyl ketone, dimethyl sulfide, ethane, ethylamine, ethyl chloride, ethyl ether, formamide, hydrogen, Hydrogen chloride, isoprene, isopropyl alcohol, lysine, methane, methyl amine, methyl ether, methyl ethyl ketone, methyl thiocyanate, methyl urea, nitric oxide, nitrogen dioxide, nitrogen oxychloride, propionaldehyde, propyl alcohol, trimethylamine, urea, uric acid, and xylose, to mention only the most volatile components.

* Taken from Meyer B., *Indoor Air Quality*

The human tolerance for various chemicals is dependent on the effect the chemical has on the human system.

Some Current Guidelines

Contaminants	Threshold Limit Value	Comfort Level
Carbon Dioxide	5,000 ppm	<800-1,000 ppm
Carbon Monoxide	35 ppm	<5 ppm
Formaldehyde	1 ppm	0.1 ppm
Ozone	0.1 ppm	N/A
Microorganisms	N/A	<800 CFU/ft^3 (22 CFU/ft^3)
Temperature	Complex formulae given in °C wet bulb globe temp.	Winter 21-23°C (70-73°F) Summer 23-26°C (73-79°F)
Relative Humidity	N/A	Winter 20-30% Summer 40-50%

Figure 8.4

Figure 8.4 lists the threshold limit values (TLV) and comfort level values. The TLV is determined by using data for a "healthy" population. The TLV is therefore, a theoretical value. The comfort level, on the other hand, is the acceptable level for an average individual. (As defined by ASHRAE, the comfort level is where 80% of the population is satisfied.)

The concentration levels for these chemicals can increase for any of the following reasons:

1. fresh air intakes at poor location (e.g. near source of combustion);
2. poor air distribution (no dilution of contaminants);
3. exhaust systems unable to expel the contaminated air;
4. newer building materials or new furniture and upholstery generating chemical contaminants.

An example of a typical ventilation system that can be the cause of poor air quality can be seen in Figure 8.5.

Carbon dioxide levels in the air are necessary for ecological balance. The buildup of CO_2 in indoor air is caused by exhaled human air and combustion processes.

As CO_2 levels are an indication of ventilation system performance, air quality testing has focused on measurement of CO_2 levels. When the concentration of CO_2 increases beyond the comfort level, concentrations should be reduced by diluting the indoor air with fresh air (provided that the fresh air available has a lower concentration of CO_2 than the air in the building).

8.4.4 Biological Contaminants

Types of Biological Contaminants

Some of the common biological contaminants found in buildings are listed below.

Contaminant	Source
Microbes	Humidifiers
Fungal spores	Humidifiers
Bacteria (pathogen)	Outdoor air, cooling towers
Allergy-causing agents (allergen)	Indoor air, pollen, & other

Biological contaminants are microorganisms which can spread through a building and be inhaled. Constant temperature levels between 15° C and 50°C (59-122° F) in stagnant pools of water provide ideal conditions for the growth of microorganisms. Such conditions are found in humidifiers and cooling towers where there is sufficient moisture and appropriate temperature for the growth of bacteria, algae and microorganisms.

Outbreaks of diseases can occur because of bacterial growth in poorly maintained humidifier equipment. Examples of bacteria-related building epidemics such as legionnaire's disease, humidifier fever and hypersensitive pneumonitis have been cited in the literature on air quality.

Concentrations of biological growth are measured in units called colony-forming units (CFU) per m^3. Concentrations exceeding 1,000 CFU/m^3 may indicate problems with biological contaminants.

8.5 Troubleshooting

The quality of air delivered to a space depends on a number of factors including the design of the building, its contents, the activities of occupants, the quality of outside air, and the design and operation of the building's heating, cooling and ventilation system. A change to any one of these elements can affect the amount of contaminants introduced into the space or the ability of the ventilation system to remove them.

For this reason, solutions to air quality problems tend to be building- and situation-specific. This makes it difficult to establish guidelines for air quality or universal troubleshooting procedures for building designers or owners.

To diagnose and correct air quality problems successfully it is important to avoid jumping to conclusions. Fear of succumbing to the indoor air quality ailment should not deter managers of buildings with energy-saving potential from proceeding with carefully engineered air system retrofits. In the same vein, increasing overall ventilation rates in buildings with air quality complaints is not the only remedy available and it may not be the most effective.

A logical approach to air quality problems includes diagnosis of the cause of the problem and the application of appropriate remedial measures.

8.5.1 Factors Affecting Air Quality

Finding the best solution to an air quality problem in a specific building requires knowledge of the building and its mechanical system as well as its environment and occupancy.

The Building

The design and construction of the building envelope will determine the infiltration rate, i.e. the rate of uncontrolled air leakage into the building. In some buildings infiltration is depended on as a source of supply for make-up air to replace air removed by exhaust appliances. Any change to the airtightness of the envelope will affect the infiltration rate and the amount of fresh air available to the building.

The materials used for interior finishes and furnishings can be the source of chemical and particulate contaminants.

When the building was designed, the mechanical system was planned to suit the layout of the interior spaces. Any changes to interior layout can have a negative impact on the effectiveness of the ventilation system in distributing fresh air, or on the exhaust system in removing contaminants.

The Outside Air

Outside weather conditions can affect the amount of infiltration and hence the supply of fresh air to the building. The quality of outside air may also vary depending on weather conditions. These variations will affect the load on the building ventilation system.

In addition, conditions around the building may change over time, thereby affecting the quality of outside air in the immediate vicinity that is available for the building. For example, an increase in traffic levels on an adjacent street or the location of an exhaust vent from a neighbouring building can affect the quality of intake air.

The Occupants

A building ventilation system is designed at the outset for a planned building use. Where there is a significant change in the number or type of occupants, either throughout the building or in a localized area, greater demands are placed on the ventilation system. For example, an increase in the proportion of chronic care patients in a home for the aged can place greater demands on the ventilation system.

Changes in occupant use of the space, such as the addition of workshops that were not planned originally, office equipment, new furnishings or new processes can introduce additional contaminants into the air. Occupant habits, particularly smoking, also have a significant effect on air quality.

Maintenance practices and cleaning agents used can also be sources of air quality problems.

The Mechanical System

The design and operation of the building mechanical system is a key factor in determining air quality. The heating and cooling functions of the mechanical system will determine the thermal characteristics of the air, which affect occupant comfort and the actions of contaminants.

The building may be ventilated in a number of ways:

- by natural ventilation through operable windows,
- by uncontrolled ventilation through infiltration, or
- by forced ventilation utilizing a mechanical system.

A forced-ventilation system can serve one or a number of purposes:

- exhaust: removes contaminants either as part of general ventilation system or on an exhaust at source basis.
- makeup: dilutes inside air contaminants by adding fresh air.
- recirculation: filtration of air and mixing of building air with fresh air.

In some buildings, the mechanical system supplies only heat and the ventilation air is provided by operable windows. Often mechanical exhaust is added to particular areas such as kitchens, and infiltration is relied on to supply the necessary makeup air. In newer sealed buildings the mechanical system supplies heating and cooling as well as all ventilation functions.

The design ventilation rate for outside air intake is only one aspect of the ventilation system. Any imbalance in the system, equipment malfunction or faulty operation of the distribution system may affect the quality of indoor air as delivered to the occupants. It is important, therefore, for building managers to know the design capabilities and limitations of the building ventilation system so that changes in factors such as the building envelope or occupancy can be accommodated.

8.5.2 Measurement and Investigation

Diagnosis of air quality problems will require measurements and investigation. The necessary measurements include: temperature, humidity, air movement, ventilation rates and CO_2 levels.

The first areas of investigation should include the mechanical system, the building and occupant use.

The Mechanical System

- Check design and maintenance factors such as adequate fan sizing, damper operation, and system balance.
- Identifiy sources of biological contaminants in building humifidication systems.

The Building and Occupant Use

- Identify potential sources of chemical contaminants such as new furnishings, office equipment, building materials or processes.

8.6 Control Strategies

Air quality control strategies can be divided into three types: source removal, exhaust at source and dilution. The choice of strategy will depend on the nature of the problem contaminant and the capabilities of the building ventilation system.

8.6.1 Source Removal

Source removal is simply the elimination of the offending element from the building. This may involve changes to activities such as building maintenance procedures or replacement of some building materials. Source removal is an effective strategy when dealing with biological contaminants and some chemical contaminants.

Biological Contaminants

Maintenance of humidifiers, appropriate location for cooling towers, and avoidance of pools of water are important in preventing uncontrolled growth of microorganisms.

Procedures such as humidifier draining and disinfection with chemical products can control the growth of microorganisms. In some cases however, humidifier cleaning is very hard to do.

The best way to reduce the growth of bacteria in the air is by using high efficiency filters.

The use of ultraviolet lamps installed in the air ducts is another way to control the growth of microorganisms. The rays emitted by the lamps kill most of the organisms. This method requires a great deal of maintenance.

In the case of steam humidifiers, it is recommended that the water be purified before it is distributed to the humidifier. Furthermore, it is important to check the steam's quality in order to avoid any movement of chemicals into building space. Volatile chemical products in water treatment can also be dangerous to the health of occupants.

In summary, humidifiers that contain water tanks kept at room temperatures offer a favourable environment for the development of microorganisms. Therefore, it is better to avoid the spread of organisms by using high-efficiency filters than to rely on proper maintenance of the humidifier.

Chemical Contaminants

Source removal measures for control of chemical contaminants include:

- changes in building maintenance to eliminate contaminants from cleaning agents, and
- changes to materials such as carpets. This strategy has been effective in some schools where worn carpets were replaced with a hard-surface flooring.

8.6.2 Exhaust At Source

Exhaust at source involves the spot removal of substances from areas such as kitchens, workshops, smoking rooms, photocopy rooms and other process operations. It is a useful strategy for some chemical and physical contaminants.

Chemical Contaminants

- Direct exhaust of air from problem areas (e.g. designated smoking areas, or photocopy rooms).

8.6.3 Dilution

Dilution involves the exhaust of a portion of the building air. The exhausted air is replaced with fresh outdoor air that is mixed with recirculated building air. This mixed air is then filtered and recirculated to the building. It is an effective strategy in dealing with some chemical and physical contaminants.

Physical

Filtration limits the spread of particulates and physical contaminants in the indoor environment. The advantages of well maintained filtration equipment are:

- protection against equipment fouling,
- increase in equipment and machinery life,
- control of physical contaminant, and
- better air quality .

Chemical Contaminants

Remedial ventilation strategies include:

- increasing outside air ventilation rates for a period of time following introduction of new materials into building spaces;
- adjusting diffuser or VAV box to correct poor air circulation; and
- modifying poorly designed or incorrectly installed ventilation equipment (e.g. outside air intake downwind of exhaust outlet).

Indoor air quality can be maintained by optimum setting of the ventilation system controls:

- optimum amounts of fresh air,
- appropriate exhausts, and
- proper control of recirculated air.

Ventilation guidelines are summarized in Figure 8.1.

8.6 Air Quality Checklist

There is no single method for improving indoor air quality. Following is a general checklist which will serve as a reference for air quality trouble shooting. Checklist numbers relate to numbers shown in Figure 8.5.

As a first step it is always useful to check air temperature and comfort criteria in problem areas.

Source Removal

1. Check for recirculation of exhaust air into outside air intake.

2. Check outside air intakes at ground level to ensure automobile exhaust or other contaminants are not introduced into outside air intake.

3. Check exhaust air systems to ensure toilet exhaust is not recirculated to return air systems. Avoid exhaust air opening near outside air intakes.

4. Check proximity of cooling tower to outside air intake. Ensure biological water treatment of cooling tower especially in summer months.

5. Avoid having stagnant pools of water on roof or near outside air intakes.

6. Check humidifier pans and sprayed cooling coils for biological contaminants or growths. Ensure proper water treatment of spray systems. Consider conversion to steam humidification.

7. Check fan coil units for stagnant water in drip pans. Ensure drip pans drain properly.

8. Check flooded carpet areas for biological contamination. Change carpet in contaminated areas.

9. Check fan rooms for solvents and other chemicals to ensure no chemical contamination is spread by air handling system.

10. Check chemicals used for rug cleaning and review concentration of cleaning agents used on rugs and floors.

Exhaust at Source

11. Check for exhaust from high humidity locations, smoking rooms, kitchens, photocopy rooms and other process applications.

Dilution

12. Check minimum outside air setting – calibrate for normal occupancy.

13. Check ambient air concentrations for CO_2 and other contaminants.

14. Adjust fan hours of operation and schedule to suit occupancy.

15. Check supply air distribution patterns to ensure adequate flushing of occupied space. Check for vertical temperature stratification as evidence of poor air distribution.

16. Adjust minimum air positions for VAV (Variable Air Volume) boxes to ensure adequate air circulation in perimeter floor space.

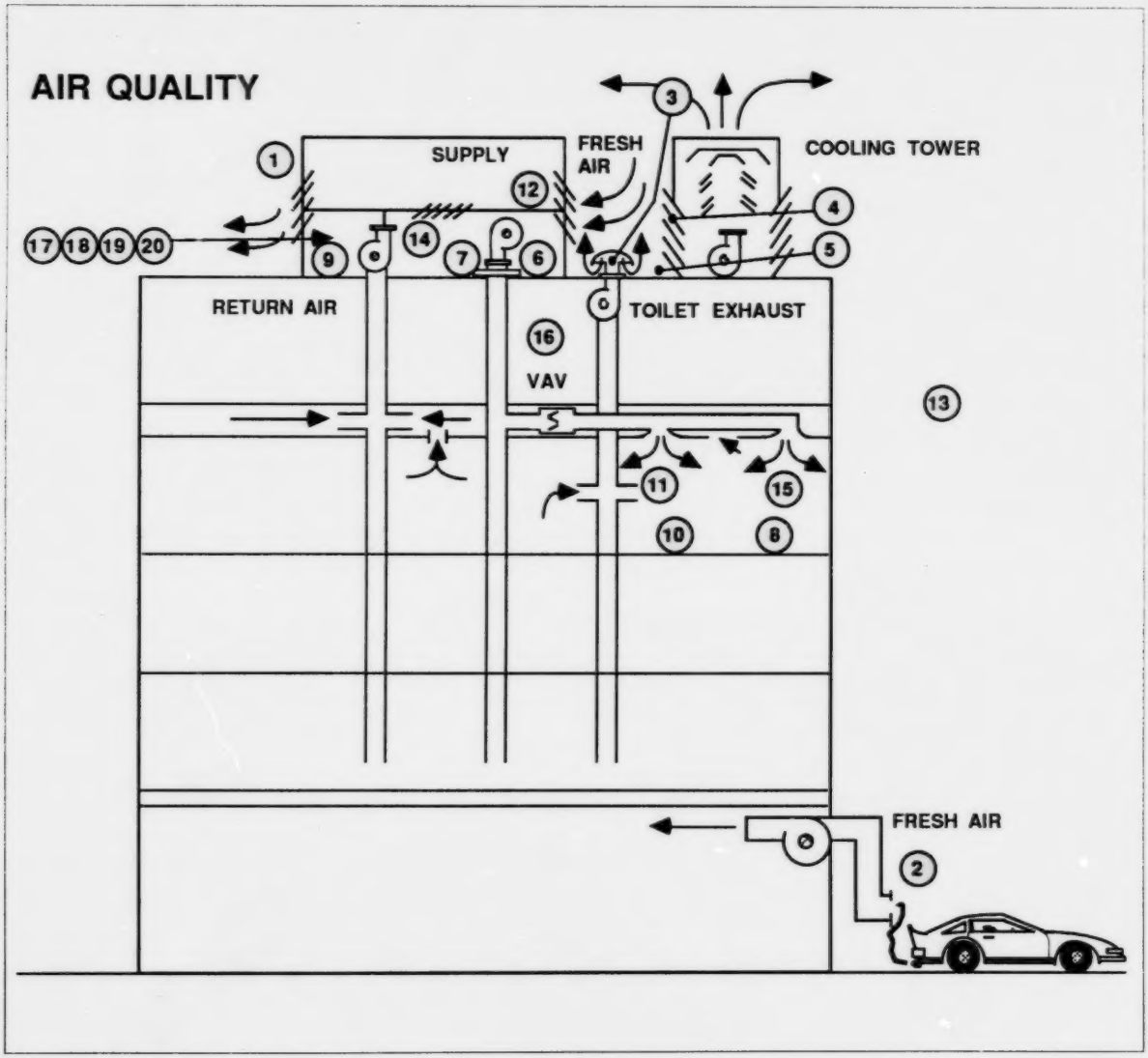
17. Provide higher ventilation rates for new buildings in first year of occupancy to deplete chemical contaminants from new furniture and carpet.

18. Filters should be selected to suit the needs of the occupants and equipment.

19. Filters should also be selected depending on the size, concentration and characteristics of the contaminants and particulates present in outside air and return air.

20. Check filters for pressure drop and ensure that replacement is done when necessary. Dirty filters will cause air distribution problems.

Figure 8.5



Lighting 9

9.1 Introduction

Lighting costs in a commercial or institutional building can account for 30 to 50% of total energy costs. Until recently, electrical costs were low and little thought was given in building design to the operational costs of lighting systems. Rather, the selection and design of lighting systems was often based on minimizing capital cost. As a result, there exists a wide range of opportunities to reduce lighting energy use in most buildings.

This chapter begins by examining the different types of lighting systems used in buildings. It explains how to begin an assessment of a building lighting system before embarking on a lighting energy management program and discusses the impact of lighting energy management on the heating/cooling requirements of the building. The effect of on/off controls on various types of lighting devices is also addressed. The final section of the chapter provides a checklist of low cost and maintenance related measures that can be incorporated into a lighting energy management program.

Lighting systems serve five distinct purposes:

1. to provide sufficient illumination to enable occupants to see and work in a productive manner;
2. to illuminate safe pathways for the movement of persons in and out of the building;
3. to complement the architectural and interior design by providing a comfortable and pleasant working environment;
4. to deter vandalism (outside lighting); and
5. to enhance or highlight a product or display.

A good source for recommended levels of lighting based on user tasks is the Illuminating Engineers Society (IES) *Lighting Handbook* (1981). Lighting levels can be easily measured and compared to recommended levels using a simple and low-cost light meter. (Note: light meters must be calibrated frequently.)

A well-designed lighting system should provide adequate and safe levels of light for the activities carried out in a space. Often, when a system is designed, the quantity (illuminance) of light is used as the only criterion for providing suitable lighting. However, recent studies have now found that the quality of light installed is also a very important factor to consider when designing or upgrading a lighting system.

Occupant visual comfort and productivity are directly related to the amount of lighting and the way it is provided. Opportunities for reducing lighting energy usage should also be looked upon as opportunities to improve the quality of lighting.

9.2 Types of Lighting Systems

Lighting units or lamps are generally divided into the three groups described below.

Incandescent Lighting

Light is produced by passing electricity through a very thin wire filament within a partial vacuum. The electricity heats the filament to a point where light is created. This type of lighting is the least efficient in terms of power consumption per light output. Incandescent light bulbs also have a relatively short life span compared to other types of lighting. However, the poor power performance of incandescent lighting is balanced against their low replacement cost, relatively small size and ease of use and control (no ballasts or transformers required).

Fluorescent Lighting

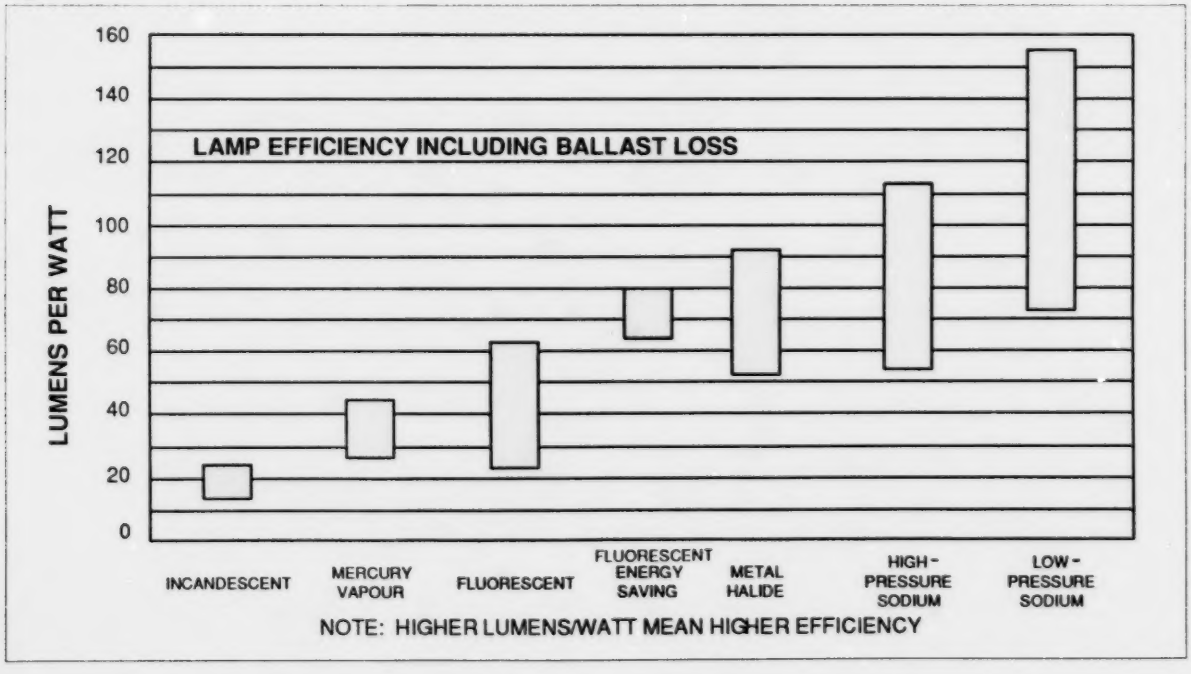
Light is created in the fluorescent tube by passing an electrical current through a tube filled with inert gases. The light produced by this current is colour-tinted by a phosphorus emulsion on the interior face of the tube. This type of lighting must be used in conjuction with a transformer ballast to regulate starting voltage.

High-intensity Discharge Lighting (HID)

HID lamps produce light by discharging electricity through mercury or sodium gas. Ballasts are also required for this type of lighting.

The relative energy efficiency of various lamps is shown in Figure 9.1. (Lamp efficacy is the term used to describe the lamp's energy efficiency.) A range of efficiency is possible for each lamp depending on lamp size and manufacturer of lamp.

Figure 9.1



9.3 Analysis of Existing Lighting Systems

Before developing an energy management program for a building lighting system, an analysis should be undertaken of the existing facilities. Information should be collected that relates to:

- the amount of light provided in each area;
- the type of fixtures and their energy consumption; and
- the occupant activity for specific lighting areas including the time period in use. (An elapsed-time meter is used to record the number of hours a lighting system has been in use over an extended time period.)

Once this information is collected, lighting levels can be compared to recommended levels. Opportunities for energy savings can then be identified:

1. reducing power consumption of fixtures through modification or replacement of fixtures or through reduced lighting levels; and
2. reducing the operating period of fixtures based on occupant activity.

The quantity of actual light output for a fixture and its energy consumption depend on the factors described below:

- operating temperature: temperature has little effect on HID lamp output;
- in-service voltage;
- type of ballast: the operating characteristic of the ballast used with the lamp will affect the lamp's light output and power requirement;
- age of the lamp: light output from lamps of different types is reduced by varying degrees over the life of the lamp;
- cleaning: frequency of cleaning lamps and reflectors will affect light output.

The quality of lighting depends on the the following factors as well as the actual level of illumination:

- geometry of the space to be illuminated,
- mounting height of lighting fixtures,
- height of work plane or area to be illuminated,
- light reflecting properties of the ceiling, walls and floor, and
- colour rendering of the particular light type under consideration.

Other factors which will affect the level of illumination in a space over time should also be considered:

- dirt on the fixture or breakdown of fixture materials may cause a decrease in reflecting ability or transparency of components of the lighting fixture;
- dirt accumulation on surfaces in the room may cause loss of light reflected to the illuminated area;
- the number of lamps which are burned out at any given time will have an obvious effect on illumination levels.

9.4 Effects of Lighting on HVAC

A final factor to be considered before embarking on a lighting energy management program, particularly for large buildings, is the effect of lighting on the heating, ventilating and air conditioning (HVAC) systems. The lighting HVAC effect refers to the impact of lighting on the heating and cooling load of a building.

Effectively all of the energy consumed for lighting ultimately ends up as heat. This heat can become a significant part of the cooling load of an air-conditioned space. The energy required to air-condition an interior space includes the energy used by the refrigerating equipment (central chiller, rooftop air conditioners or window type air conditioners). It may also include pump energy to deliver chilled water to the space, and fan energy to deliver cool air. All of these components can be reduced in size if heat output from lights is reduced.

Conversely, reducing the energy use of lights increases the heating load of a space in winter, since the heating effect of lights is reduced. This "HVAC effect" of lighting on heating and cooling must be calculated when planning lighting measures.

9.5 On/Off Control of Lighting

When considering operating time, the type of light sources to be switched on and off must first be taken into consideration. Incandescent lamps are compatible with all on/off control devices. Frequency of switching has no effect on incandescent lamp life.

However, fluorescent lamp life is shortened by very frequent on/off switching. Generally, it is economical to shut fluorescent lights off for 10 minutes or longer.

High-intensity Discharge (HID) lamps cannot be switched as conveniently as fluorescent and incandescent lamps because of their characteristic re-light time of up to several minutes.

Automatic control is often the most convenient and cost-effective method of switching lights off.

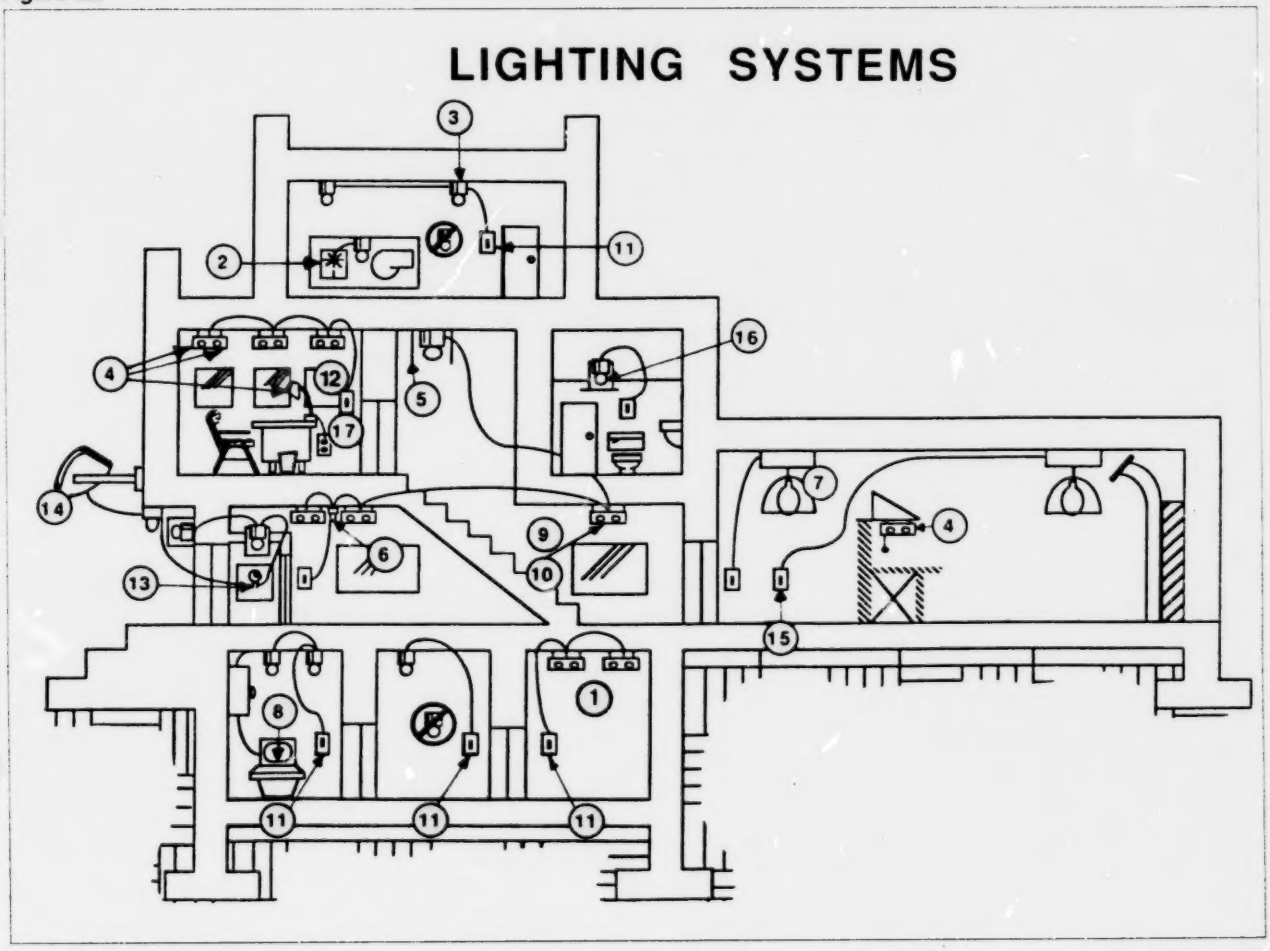
9.6 Lighting Energy Management

The energy management measures referred to in this section are divided into two catagories:

- Low-cost Capital Improvements, and
- General Maintenance and Operation.

Each of the numbered initiatives from 2 to 17 in this section refers to Figure 9.2.

Figure 9.2



9.6.1 Low Capital Cost Improvements

1. Reduce Lighting Levels
Reduce lighting levels where possible through de-lamping, permanent removal of fixtures or use of current limiting devices for fluorescent lamps. Obtain professional advice before proceeding with these measures.

2. Add Pilot Lights
Add pilot lights on light switches for lights installed in large air-handling units. Pilot lights will show when the light is on.

3. Replace Incandescent Lighting,
Replace incandescent lamps with fluorescent lamps wherever possible by use of screw-in fluorescent lamps.

4. Convert To Task Lighting
Install light source as close as possible to the working station with a local light switch, then reduce general lighting level. Or, as an alternative method, divide general lighting into sections with local switching such as:

- movable lights for working stations,
- lights at working stations,
- lights in conference rooms, and
- lights in corridors and other travel areas.

Then adjust lighting levels of all areas according to recommended lighting levels (see *IES Handbook*, 7th edition).

5. Use More Efficient Light Source
Where inefficient lighting sources (incandescent) are required to operate more than 60 hours per week, consider changing light source to a more efficient source (fluorescent).

In hard-to-reach areas, this measure is even more cost-effective since fluorescent lighting has a life expectancy 10 to 20 times longer than incandescent lighting. Where colour rendition is not important consider HID lamps for replacement of incandescent fixtures (e.g. outside lighting, lighting for night security, storage rooms, garages, etc.)

6. Photocells
With adequate natural light, turn lighting fixtures off with interior photocells.

7. High-efficiency Lamps
In shops and garages, use high-efficiency lighting fixtures when the number of hours of operation will justify the retrofit costs.

Also consider replacing standard fluorescent lamps when burned out with energy-efficient lamps where lamp/ballast combinations are compatible.

Note: High-intensity mercury lamps are less efficient than fluorescent tubes whereas high pressure sodium lamps are more efficient. Low-pressure sodium lamps are the most efficient. Also, do not use energy-efficient fluorescent lamps in areas where the temperature falls below 15°C (59°F).

8. Automated Lighting Control Systems
In buildings with large lighting loads, scheduling of lighting loads can be managed by automated control systems with scheduling and override capability. Photocells can be used to turn off outside lights during the day, or a timer can be used for HID lighting. Energy cost savings relate primarily to savings in electrical energy rather than electrical demand. Obtain professional advice before proceeding with this measure.

9. High-efficiency Ballasts
When ballast failures occur, replace existing ballasts with energy-efficient-type ballasts. High-efficiency ballasts can be justified when lighting hours of operation are sufficient to pay back premium cost of ballast. If hours of use for lighting exceed 2,500 hours per year, the premium cost of high-efficiency ballast is likely justified.

10. Lighting Reflector Kits
Reflector kits for light fixtures can be installed to increase light output and reduce the number of tubes required in each fixture. Obtain professional assistance before proceeding with this measure.

Also, when redecorating, consider using lighter colours for ceilings and walls to provide better reflection.

9.6.2 General Maintenance and Operation

11. Manual Control Of Lighting
Instruct maintenance staff and operating personnel to turn off lights when leaving penthouse; add a reminder near all light switches. Also, instruct housekeeping personnel to turn off lights when their cleaning task is completed.

If cleaning is done during working hours, consider connecting lighting fixtures in parallel with other equipment controlled by a timer to shut off lights when building is unoccupied.

12. Use Natural Light
Direct occupants to take advantage of natural illumination when available if the light switches make it possible.

13. Reduce Night Lighting
In vestibules and hallways reduce lighting to minimum levels when the building is unoccupied.

14. Reduce Architectural Lighting
Do not use architectural lighting unless needed for the purpose of appearance.

15. Reduce Illuminated Areas
Match lighted areas to working areas.

16. Pot Lights
Replace incandescent bulbs in pot lights with screw-in type fluorescent lamps with reflectors.

17. Dimmers
Use light dimmers where appropriate. Caution: resistance-type dimmers do not save energy as they simply convert energy not used for lighting to heat. Electronic dimmers are preferred.

Building Automation Systems 10

10.1 Introduction

This chapter describes the features of an automated control system that can be utilized in conjunction with an energy management program. The various control and component options are discussed as well as the features of the various types of systems.

The last section of this chapter examines a process that can be used to select a building automation system and some of the common problems that have occurred once a system has been installed.

Many old buildings have more than adequate heating and cooling capacities. However, comfort and operational problems are experienced owing to antiquated controls. Installing a building automation system not only saves money by reducing unnecessary energy consumption, but it can also increase the level of comfort significantly.

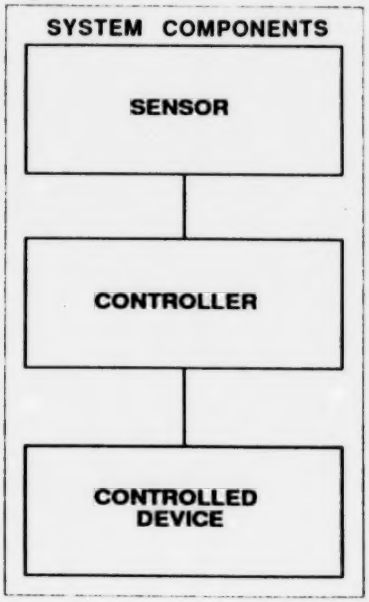
A building automation system can be as simple or complicated as the building owner wishes. Buildings as small as 470 m^2 (5,000 ft^2) can benefit from an energy management system.

10.2 The Control Function

All building control systems incorporate three basic components:

1. sensors to measure,
2. controllers to regulate equipment, and
3. operating equipment.

Figure 10.1



An example of a sensor is a temperature sensor which sends a pneumatic or electronic signal proportional to the temperature back to a controller.

Controllers are designed to receive sensor inputs, compare the input to a setpoint and send a signal output to a controlled device. An example of a controller would be a pneumatic controller which varies air pressure.

The operating equipment is any device connected to and operated by the controller. Typical examples are valves and damper motors in commercial buildings.

Typical Control Systems

The conventional control system utilized in most buildings is a pneumatic control system as shown below.

The same type of control can be accomplished using electronic controls. In this type of system, the control system will use direct current (DC) voltage for powering the controlled device rather than air pressure. Currently, pneumatic control systems tend to be more prevalent than electronic controls because of lower installation costs.

The control function can also be performed by a computer or microprocessor. A microprocessor or computer can respond to software programs and can be used to operate in conjuction with a wide variety of sensors and equipment.

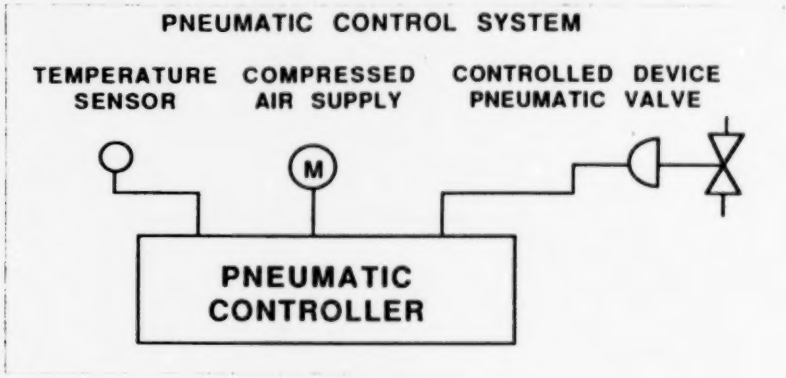


Figure 10.2

Supervisory Computer Control

In this type of control system, a computer is installed to supervise the operation of the existing control mechinism. The supervisory control method shown above combines a computer-based monitoring and decision- making system with an existing pneumatic (or electronic) control system. A new set of electronic sensors is installed to provide direct input to the computer. In most cases the electronic sensors are more reliable and do not require constant recalibration.

The computer is programmed to read the temperature signal and provide an output signal for resetting the pneumatic controller. An E/P (electronic to pneumatic) transducer is used to convert the electronic signal to a pneumatic pressure, which in turn resets the controller according to the computer's instructions. If the computer should fail, the pneumatic system will remain operational if the sensor is retained and the sensor is properly calibrated. A disadvantage of supervisory control is that two systems must be maintained.

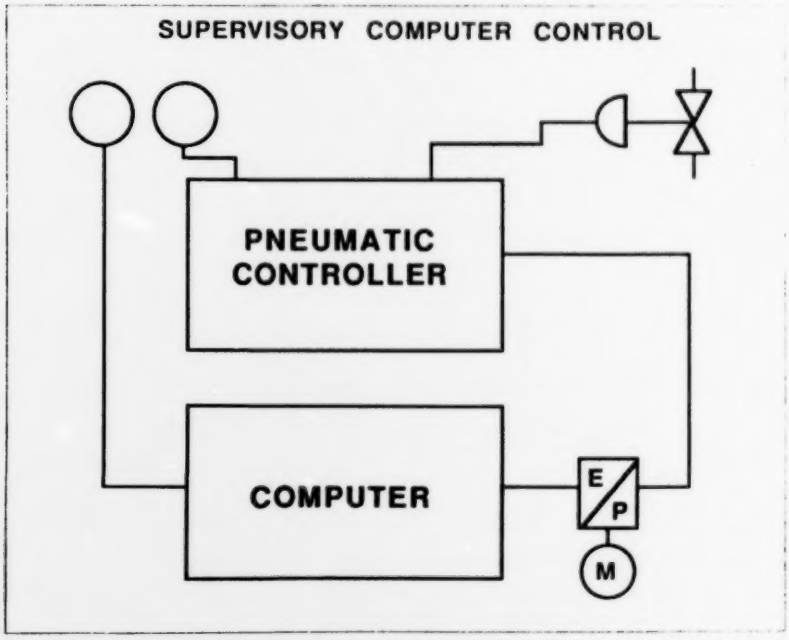


Figure 10.3

Direct Digital Control

Another method of computer control is referred to as direct digital control. In this type of system, the computer controls the operation of equipment directly performing the function of a pneumatic or electronic controller.

When converting an existing pneumatic system to direct digital control, conversion of the pneumatic actuators (e.g. valves and switches) of the operating equipment is often not economical. Pneumatic actuators are less expensive to purchase and usually require less maintenance than motor-driven actuators. As a result, a transducer can be installed to convert the digital operating signal into a pressure that the actuator on the equipment can understand. The example in figure 10.4 demonstrates how a transducer can be incorporated into a system. Using a direct digital control does not necessarily mean that pneumatic actuators must be eliminated.

Systems using direct digital control must rely on the computer to operate the system at all times. If the computer fails, the control system will not operate.

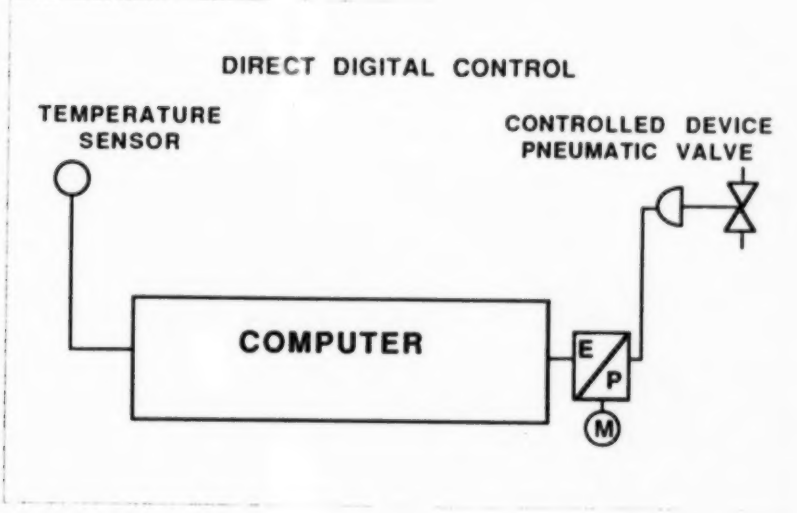


Figure 10.4

10.3 Applications of Building Automation Systems

There are a number of reasons why a building operator or manager might want to incorporate an automated control system into a building:

- to improve building operation and comfort;
- to increase building safety or security;
- to reduce operating costs including energy costs; or
- to provide more efficient building management.

Depending on the actual need, control systems can be purchased that will incorporate one or all of the functions listed above. However, this section will focus primarily on the various control options for energy management made possible with an automatic control system. A later section of this chapter outlines the actual process by which you can determine your building needs, including the need for safety and security functions.

A brief discussion of the various control options that can be incorporated into a computer- controlled, automated system follows.

Programmed Start/Stop
Programmed start/stop is a software based logic that permits the user to schedule starting and stopping of equipment according to a predetermined schedule. Each piece of equipment can operate on its own schedule. Operating schedules optimize equipment use by allowing operation only at appropriate times. Moreover, one can reduce peak electrical demand charges that may result from simultaneous operation of equipment.

Alarms/Monitoring
This type of software based logic signals an alarm or initiates a particular action when an upper or lower limit has been exceeded. Temperature, pressure and liquid levels as well as equipment run-time are usually supervised by this type of software.

Energy Monitoring
This function allows the recording and accumulation of fuel and electricity consumption data, allowing for improved analysis of the consumption rate of fuel and electricity. Additional computer software can be used with this and other data collected by the computer to analyze energy performance of the system and its individual components.

Demand Control
This software feature reduces electrical power demand by stopping or delaying the operation of certain pieces of non-essential electrical equipment during peak demand periods. The equipment is restarted automatically as soon as a peak crisis has passed.

Duty Cycling
This software executes the stop/start cycles for equipment. One can therefore avoid the simultaneous operation of several loads that do not require continuous operation and limit the energy consumption of all the controlled equipment. This software is well suited to control the operation and control of refrigeration compressors, heating elements for snow melting or heating pumps.

Optimized Stop/Start
This type of program logic calculates the best time to initiate preheating or precooling of the building. It can also modulate equipment on/off operation to minimize operating time. At the same time the system monitors temperatures to ensure that optimum occupant comfort is maintained. A frequent application of this software is to control the operation of a heating system after a temperature setback cycle (night setback).

Optimized Ventilation
This software is used to optimize the blending of outside air and return air based on the enthalpy of the two air streams. It is designed to maximize free cooling and enthalpy control. This software is employed, of course, only for ventilation systems allowing a mixture of return air and outside air.

Optimization of Supply Air Temperature
This software allows the adjustment of supply air temperature as a function of the heating and cooling loads of the building. This software can be utilized with double-duct, multi-zone reheat, and variable-air-volume systems. By interactively adjusting the supply air temperature according to the changing heating/cooling loads of the building, this type of software control minimizes energy costs.

Chiller/Boiler Optimization
When the cooling system comprises several chillers, this type of logic operates the minimum chilling capacity to satisfy the load. Where equal sized chillers are involved the logic alternates the sequence of chiller selection to equalize/balance run-time (this is often referred to as "lead-lag" control). Similar logic can be used for boiler optimization.

Supply Water Temperature Optimization
This type of control can regulate the chilled water and hot water supply temperatures of the cooling/heating systems as a function of the actual demand of the building. To minimize loss of energy, the software reduces the temperature of the hot water supply and increases the temperature of the chilled water supply while still ensuring that adequate space conditioning is provided.

Temperature Setback/Setup
Temperature setback/setup type of controls provides for scheduling of building space temperatures during unoccupied periods. Heating energy can be saved by programming a setback temperature in winter and cooling energy can be saved by programming a setup temperature in summer.

Other Control Options
There are several other control options available with building automation systems including the following:

- lighting control for exterior and/or interior lighting and security;
- domestic hot water optimization, where the temperature of hot water is matched to the building demand profile;
- cistern flow optimization, which modulates water flow to cistern-operated urinals; and
- options for specialized applications such as swimming pools.

10.4 Types of Building Automation Systems

Building Automation Systems (BAS) include systems which control energy management functions as well as systems which control other building management functions such as security. Building automation systems can be classified by:

- the number of control points,
- the means of control, and
- the type of data communication used between the controller and the control points.

The features of various types of building automation systems (BAS) are outlined below.

Single Function Systems

- non-computerized controllers
- usually one or two control points
- hardwired logic
- specific use such as time clock, temperature setback

Multi-function Microprocessor

- microprocessor-based
- multi-point – most common 8 or 16 control points
- variable settings
- programmable logic
- sensors and controlled devices hardwired to microprocessor

Central Station Computers

- microprocessor-based
- multi-point more than 16 point capability
- centralized system for all points
- can use power line carrier communication
- programmable logic for selected energy management routines

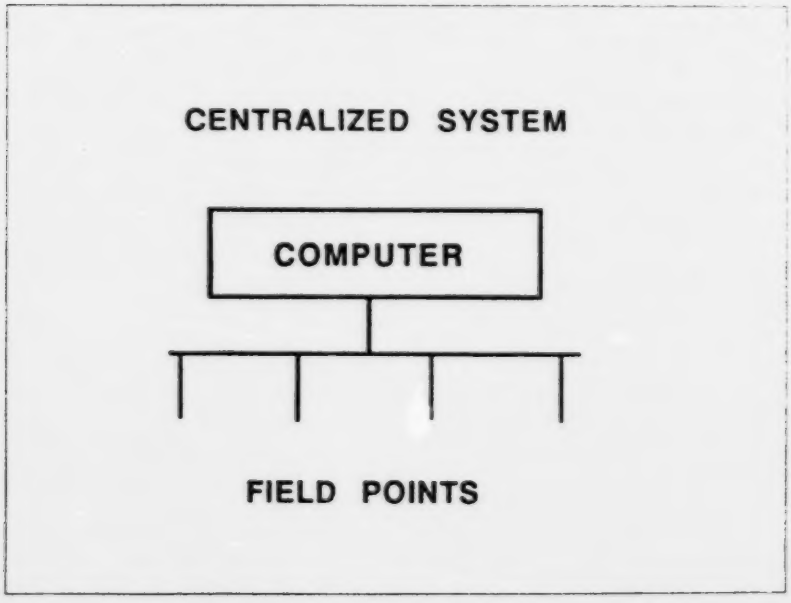


Figure 10.5

Central Station — Distributed Intelligence

- central computer station
- large multi-point control capability
- field panels with limited intelligence capability
- programmable software for energy management functions
- limited programming available at field panels
- sensors and controlled devices wired to field panels
- data communication by several media possible, e.g., twisted-pair-wired, telephone lines, coaxial cable or power line carrier

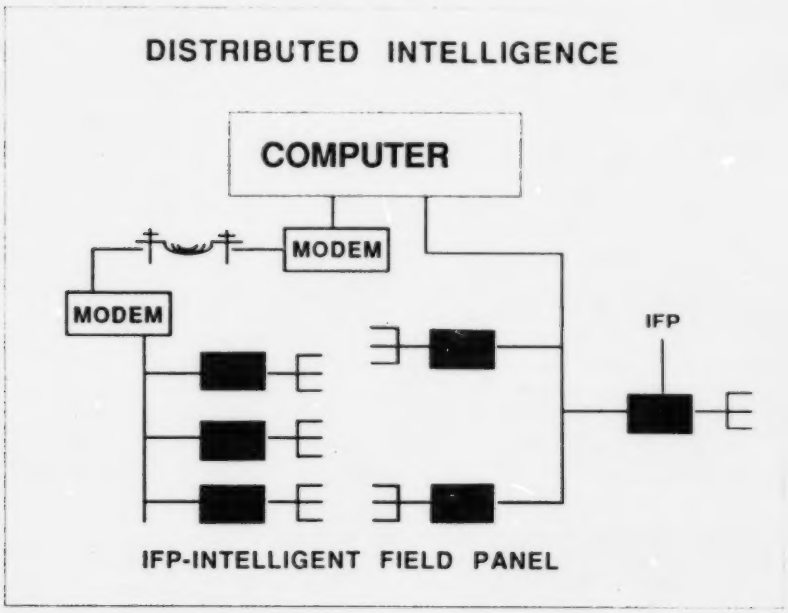


Figure 10.6

Fully Distributed Intelligence

- multi-function microprocessors in field panels
- large multi-point capability
- no requirement for central computer
- field panels perform all or most software functions
- sensors and controlled devices wired to field panels

Choosing the Best System

The design of a central computer system is compared to the fully distributed computer system in Figures 10.5 and 10.6. Fully distributed systems reduce wiring costs for large buildings and provide greater reliability since more than one computer is used. The type of building, distribution and number of control points will determine the best value system for each application. In many applications, the simple, single function system may provide the best value.

10.5 Selection of a Building Automation System

The selection of a BAS is based on the requirements for a particular building. The requirements should be carefully reviewed before attempting to select any control equipment. An outline of the likely steps involved in the selection process for a building automation system is presented below.

Planning

- definition of requirements
- information retrieval
- field survey in building
- identification of remedial measures for existing control systems
- identification of equipment modifications
- energy software options

System Design

- control point selection
- system design configuration
- communications co-ordination
- data transmission media configuration
- field equipment locations
- central control room design and location
- instrumentation and controls design
- wiring requirements
- transient lightning voltage protection

Contract

- contract documentation
- drawings
- specifications

The building owner/manager may wish to retain a qualified consultant to manage the selection process and prepare a suitable specification for public tender. At a minimum, the building owner/manager should be involved in the definition of requirements and the control point selection. Each control point will cost between $250 and $1,000 to add to the system. Consequently, each control point should be carefully reviewed and justified before selection. Avoid over-controlling a given process and avoid duplicating functions that are better or equally well performed by the existing pneumatic control system.

The Building Automation System software is critical to the effective operation of the building controls. Care should be taken to review the software applications and investigate existing installations of the vendor's software/hardware. A careful review of existing installations will provide valuable information for the selection process.

Appendix 1: Measuring Energy

Building energy is used in a variety of forms such as electricity, natural gas, heating oil, coal, wood, or propane. Occasionally thermal energy is received directly, such as steam for heating, or chilled water for cooling. The different forms of energy are measured in different units. The units of measurement of energy currently in use in Canada are described below.

ENERGY SOURCE	UNITS OF MEASURE
electricity	demand rate: Kilowatt (kW)
	consumption: Kilowatt hour (kWh)
natural gas	Cubic meter (m^3)
	Hundred cubic feet (ccf)
	Thousand cubic feet (mcf)
oil	Litre (L)
	Imperial gallon (gal)
steam	Kilogram (kg)
	Pound (lb)
	Thousand pounds (Mlb)
propane	Litre (L)
	Imperial gallon (gal)
coal	Kilogram (kg) / Pound (lb)
	Ton / Tonne

A description of these units may be found below.

Electrical Consumption – kWh
Electricity can be thought of as a flow or current of electrons. Electric meters measure the amount of this flow. The rate of electron flow (the current) is measured in amperes. The "pressure" under which electrons flow is measured in volts. The product of the two is the power, measured in watts, that the electric meter measures and records.

Since a watt is a very small amount of power, we usually express the power in a larger unit, the kilowatt, which means one thousand watts.

If we use energy at the rate of one kilowatt, for one hour, we have consumed one kilowatt-hour. This is the energy unit that the utility uses for billing purposes.

Electrical Demand – kW
Electrical demand is a measure of the RATE at which we use energy. Most utilities provide a separate charge based on the highest (i.e. peak) rate at which energy is used or demanded in a billing period. This is called Peak Demand for a billing period.

Gas - m^3, mcf, ccf

Natural gas is delivered as a flow of gas volume through the pipe. The amount of gas a building uses can be expressed as the volume of gas delivered, measured in cubic feet or metres (m^3).

The amount of gas in a given volume varies with the gas pressure, and the gas company corrects for pressure differences when billing.

By law every m^3 of gas billed must be able to provide a certain minimum amount of heating energy.

Steam – kg
Steam quantities are measured as a flow but expressed in weight units such as pounds or kilograms of steam. As the amount of heat contained in a kg of steam varies with the steam pressure, the measured kg of steam is usually related to a basic steam pressure defined in the agreement with the utility.

Water, Heating Oil – Litres
Water and heating oil by comparison are measured by liquid volume. The volume is simply expressed in terms of litres.

There are some exceptions to this rule. If we buy water for heating or cooling, we really are not buying the water, but the heating or cooling capacity of that water. The billing process, therefore, not only has to reflect the volume of water but the temperature differential between supply and return water.

Heavy heating oil or bunker oil is viscous at room temperature. It is heated for delivery, in order to facilitate pumping it from the delivery truck to the tank. Because the oil expands with heat and increases in volume, the bill is corrected for temperature.

Appendix 2: Metering Energy

Most sources of energy, such as electricity, natural gas, steam and water, enter in a continuous flow. Meters detect the rate of flow, calculate, and record the total quantity supplied. In the case of electricity the meter may also indicate the highest rate of flow, or peak demand, during a given time period.

The following is a brief description of the types of equipment commonly used to meter energy.

Electrical Energy and Demand Meters

ENERGY = POWER x TIME (kWh = kW x h)

An electrical meter performs this calculation, using a disk whose speed of rotation is proportional to the power (watts) drawn through the meter. Watt-hours are calculated by summing over time the number of revolutions of the rotating disk.

The revolutions are accumulated in a kilowatt-hour register. The gearing of the register is designed so that the number of revolutions corresponds to the kilowatt-hours of electrical energy which have been consumed.

Smaller commercial customers are usually supplied with meters which measure kilowatt-hours and kilowatts of peak demand on the same meter. This is achieved by incorporating both a kilowatt-hour and demand register which are both driven by the rotating element.

Large commercial and industrial customers usually have their demand peak recorded by means of a pulse-operated demand meter.

Gas Meters

One way to view the operation of a gas meter is the concept of filling and emptying a measuring cup of known volume. The total volume measured would be the number of times this measuring cup was filled and emptied multiplied by the volume of the cup. In a small gas meter, there are two bellows which are alternately filled from the supply line and emptied into the system. The register counts the number of bellows emptied and multiplies it with the volume of the bellows. The result is displayed on a digital read-out or a series of dials.

Ambient temperature and delivery pressure will affect the volumes measured – the meter adjusts for this by using internal pressure-reducing valves.

Large gas meters use small turbines which are spun by the gas as it passes through. As in the electrical meter, the higher the gas flow the faster the rotation of the turbine and the more units accumulated in the counter. In order to correct for fluctuations in pressure and temperature, both are recorded on a continuous chart recorder. When the gas meter is read, the charts are taken back to the gas company and used to arrive at the proper amount of gas for billing.

Steam Meters

Steam meters also use a turbine device for measurement. As with natural gas, the steam pressure has a direct bearing on the quantity of steam flowing through the meter and a correction factor must be applied to the meter display to obtain the correct steam quantities.

Flow meters used for steam and gas measurement state their accuracy for a stated range of flows. Outside of that range (if very low or very high flow rates) accuracy of the meter is not assured.

Water Meters

Water meters are of two types. Small ones use a wobbler, a version of the "measuring cup". Very large ones use turbines. Intermediate ones use a combination of both devices and require a summation of two readings to give total use. Water temperature will affect accuracy. Water meters are usually specified for cold water use, or for specific ranges of temperatures of hot water.

Oil Meters

Most oil is delivered to buildings in measured quantities. The amount used by heating systems is usually not metered by oil meters in the building. Three options for measuring oil flow are:

1. metering using a flow meter,
2. measuring volumes in storage tanks, and
3. estimating use based on hours of burner operation at a known rate of oil use by the burner.

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